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Developing Emergency Preparedness Plans For Orlando International Airport (MCO) Using Microscopic Simulator WATSim

Daniel Dawson
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**DEVELOPING EMERGENCY PREPAREDNESS PLANS FOR ORLANDO
INTERNATIONAL AIRPORT (MCO) USING WATSIM**

By

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2001

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

Emergency preparedness typically involves the preparation of detailed plans that can be implemented in response to a variety of possible emergencies or disruptions to the transportation system. One shortcoming of past response plans was that they were based on only rudimentary traffic analysis or in many cases none at all. With the advances in traffic simulation during the last decade, it is now possible to model many traffic problems, such as emergency management, signal control and testing of Intelligent Transportation System technologies. These problems are difficult to solve using the traditional tools, which are based on analytical methods. Therefore, emergency preparedness planning can greatly benefit from the use of micro-simulation models to evaluate the impacts of natural and man-made incidents and assess the effectiveness of various responses. This simulation based study assessed hypothetical emergency preparedness plans and what geometric and/or operational improvements need to be done in response to emergency incidents. A detailed framework outlining the model building, calibration and validation of the model using microscopic traffic simulation model WATSim (academic version) is provided. The Roadway network data consists of geometric layout of the network, number of lanes, intersection description which include the turning bays, signal timings, phasing sequence, turning movement information etc. The network in and around the OIA region is coded into WATSim with 3 main signalized intersections, 180 nodes and 235 links. The travel demand data includes the vehicle counts in each link of the network and was modeled as percentage turning count movements. After the OIA network was coded into WATSim, the road network was calibrated and

validated for the peak hour mostly obtained from ADT with 8% K factor by comparing the simulated and actual link counts at 15 different key locations in the network and visual verification done. Ranges of scenarios were tested that includes security checkpoint, route diversion incase of incident in or near the airport and increasing demand on the network. Travel time, maximum queue length and delay were used as measures of effectiveness and the results tabulated.

This research demonstrates the potential benefits of using microscopic simulation models when developing emergency preparedness strategies. In all 4 main Events were modeled and analyzed. In Event 1, occurrence of 15 minutes traffic incident on a section of South Access road was simulated and its impact on the network operations was studied. The averaged travel time under the incident duration to Side A was more than doubled (29 minutes, more than a 100% increase) compared to the base case and similarly that of Side B two and a half times more (23 minutes, also more than a 100% increase). The overall network performance in terms of delay was found to be 231.09 sec/veh. and baseline 198.9 sec/veh. In Event 2, two cases with and without traffic diversions were assumed and evaluated under 15 minutes traffic incident modeled at the same link and spot as in Event 1. It was assumed that information about the traffic incident was disseminated upstream of the incident 2 minutes after the incident had occurred. This scenario study demonstrated that on the average, 17% (4 minutes) to 41% (12 minutes) per vehicle of travel time savings are achieved when real-time traffic information was provided to 26% percent of the drivers diverted. The overall network performance in delay for this event was also found to improve significantly (166.92 sec/veh). These findings led to the conclusion

that investment in ITS technologies that support dissemination of traffic information (such as Changeable Message Signs, Highway Advisory Radio, etc) would provide a great advantage in traffic management under emergency situations and road diversion strategies. Event 3 simulated a Security Check point. It was observed that on the average, travel times to Sides A and B was 3 and 5 minutes more respectively compared to its baseline. Averaged queue length of 650 feet and 890 feet worst case was observed. Event 4 determined when and where the network breaks down when loaded. Among 10 sets of demand created, the network appeared to be breaking down at 30% increase based on the network-wide delay and at 15% based on Level of Service (LOS). The 90% increase appeared to have the most effect on the network with a total network-wide delay close to 620 seconds per vehicle which is 3 and a half times compared to the baseline.

Conclusions and future scope were provided to ensure continued safe and efficient traffic operations inside and outside the Orlando International Airport region and to support efficient and informed decision making in the face of emergency situations.

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TABLE OF CONTENTS

LIST OF FIGURES	x
LIST OF TABLES	xii
LIST OF EQUATIONS	xiii
CHAPTER ONE INTRODUCTION	1
Thesis Goal and Objectives	3
Thesis Contributions	3
Thesis Layout	4
CHAPTER TWO LITERATURE REVIEW	5
Strengths and limitations of simulation modeling	5
Traffic Simulation Models	11
Problem Solving Methods	12
Applications of Simulation Models	14
Evaluation of Simulation Tools	21
Weaknesses	24
Summary	25
CHAPTER THREE METHODOLOGY	26
CHAPTER FOUR MICROSCOPIC SIMULATOR - WATSim	28
Overview	28
WATSim Operating Characteristics and Features	30
Animation Displays	31
How large an area can be simulated with WATSim?	32

Input Data Requirements	32
Traffic Generation and Assignment.....	33
Traffic Control	34
Multi-Modal Transportation	35
Measure of Effectiveness (MoE)	35
UNITES Overview	35
UNITES Network Editor	37
Specific WATSim Network MoEs	38
Vehicle Type Specification.....	38
Statistics	39
CHAPTER FIVE ORLANDO INTERNATIONAL AIRPORT (OIA).....	40
Introduction.....	40
The OIA Road Network Description	40
OIA Road Network Data Collection.....	43
OIA Model Development	44
OIA WATSim Model Dataset Coding.....	45
Signal Control Coding	46
Coding of Re-circulating Volume.....	48
CHAPTER SIX MODEL CALIBRATION AND VALIDATION	52
Introduction.....	52
Initial Model Calibration and Validation Analysis.....	55
Queue Formation at Terminals	56
Selection of Measures of performance of OIA WATSim Model.....	56

Determination of Number of Simulation Runs.....	57
Analysis of Calibration and Validation Results.....	62
Model Validation Requirements.....	68
Variance Ratio F-test	71
Description of the Hypothetical Emergency Events and Simulation	73
Summary of Overall Network-wide Performance for All Scenarios.....	90
CHAPTER SEVEN CONCLUSIONS AND FUTURE SCOPE.....	92
Summary and Conclusions	92
Suggested Future Works.....	98
APPENDIX A: SEMORAN/LEE VISTA PHASING PLAN & CONTROL CODE	100
APPENDIX B: SEMORAN/T.G LEE PHASING PLAN & CONTROL CODE	102
APPENDIX C: SECURITY CHECKPOINT PHASING PLAN & CONTROL CODE	104
LIST OF REFERENCES	107

LIST OF FIGURES

Figure 1. Problem solving methods for a system represented in a chart	13
Figure 2. WATSim ITS Application to San Francisco Embarcadero road network ..	16
Figure 3. Unites Architecture.....	37
Figure 4.OIA Aerial View of study area.....	42
Figure 5. Typical Simulation Steps.....	44
Figure 6. Background DXF File of OIA Area network in the UNITES Editing Window.....	45
Figure 7. Base Network of OIA showing Nodes and Links	47
Figure 8. Snapshot of Animated Base Network of OIA in WATSim	50
Figure 9. Snapshot of WATSim Simulation of Terminal A with Circulating Traffic	51
Figure 10. Snapshot of WATSim Simulation of Terminal B with Circulating Traffic	51
Figure 11. Map showing the fifteen key link locations selected for statistical investigation of model.....	65
Figure 12. Comparison of traffic volumes from simulation model and field counts..	69
Figure 13. Incident location on South Access Road Northbound direction without diversion.....	74
Figure 14. Incident with diversion at South Access Road and Heintzelman intersection.....	76
Figure 15. Location of Security Checkpoint.....	80
Figure 16. Snapshot of Base Conditions.....	84
Figure 17. Snapshot of Base condition at Terminal A.....	84

Figure 18. Effect of 70% increase in demand.....	85
Figure 19. Effect of 70% increase in demand at Side-A.....	85
Figure 20. Effect of 80% increase in demand.....	86
Figure 21. Effect of 80% increase in demand at Side-A.....	86
Figure 22. Effect of 90% increase in demand.....	87
Figure 23. Effect of 90% increase in demand at Sides A & B.....	87
Figure 24. Overall network-wide performance for all scenarios	90

LIST OF TABLES

Table 1. HCM interpretation of Simulation Model	8
Table 2. Summary of previous traffic simulation comparisons	22
Table 3. Evaluation of PARAMICS and WATSim capabilities based on their ability in simulating real traffic conditions	23
Table 4. Peak Hour Re-circulatory Volume Analysis Summary	48
Table 5. Determination of Number of Simulation Runs	60
Table 6. RE and GEH Statistics for 15 selected key link locations without circulation traffic	66
Table 7. RE and GEH Statistics for the 15 selected key link locations with circulation traffic	67
Table 8. T-Test of Field and Simulated Data Counts for the 15 key link locations ...	70
Table 9. Event 1: Travel time measured from intersection of South Access and Heintzelman roads to sides A and B	75
Table 10. Event 2: Northbound South Access without diversion	77
Table 11. Event 2 Diversion through Heintzelman Blvd	78
Table 12. Event 3: Travel time to sides A and B	80
Table 13. Event 3: Security check point (SB Semoran Blvd)	81
Table 14. Event 3: Security checkpoint (SB Semoran Blvd) worst case	81
Table 15. Demand set created for the four major entry points	82
Table 16. Overall network-wide Performance for all scenarios in Event 3	88
Table 17. LOS Summary for Selected Links	89
Table 18. Network-wide comparison of Delay for all Scenarios	90

LIST OF EQUATIONS

Equation 1:	34
Equation 2:	54
Equation 3:	54
Equation 4:	57
Equation 5:	62

CHAPTER ONE

INTRODUCTION

In case of emergencies, good transportation system operations are essential to ensure safe, continuous movement of people and goods as well as support response and recovery operations. Therefore, it becomes important to ensure the operation and integrity of the transportation system and enhance its ability to provide service in the event of an emergency through strategic planning and active management. An important step toward this direction is emergency preparedness (Sisiopiku et al., 2004).

In the event of a natural or man-made disaster, emergency preparedness plays a vital role in ensuring the safety, security, and efficiency of the transportation system. Emergency preparedness greatly depends on the understanding of the scope and magnitude of potential incidents and the significance of their disruptions to the mobility of people and goods in the transportation system. Preparedness involves anticipating a range of emergency scenarios and developing and testing plans to respond to them.

Emergency preparedness for a state or locality is often measured in terms of its ability to respond to an emergency in a timely and effective manner. In the case of emergencies that affect the transportation system, the response time is a critical factor in minimizing adverse impacts including fatalities and loss of property.

Following the events of September 11, 2001, the transportation community recognized the need for better emergency planning and prevention, crisis

management, and response to threats and disasters affecting the operation of the transportation system. So far a lot of emphasis has been put on developing policies and procedures, improving the infrastructure, and training first respondents and agency officials in an effort to prevent, respond and recover from potential acts of terrorism and other disasters. While many communities have been actively involved in the development of emergency plans, more emphasis needs to be put toward assessment, comparison of alternative options, and refinement of the proposed plans to achieve improved solution. Toward this direction, this study looked at the potential of traffic simulation as a tool for evaluating various strategies involving emergency preparedness. Traffic simulation models have become widely used over the past decades and can allow detailed traffic operation analysis to support decision making. The use of simulation enables the user to test different transportation related emergency preparedness strategies under a range of different emergency situations without the cost and risk involved in carrying out actual tests.

With increased interests and awareness in emergency preparedness and first responder access to emergencies in public locations (airport, transit station, port or stadiums, etc), one of the related issues affecting the Orlando International Airport (OIA) is how to evaluate the effectiveness of emergency readiness plans when faced with some hazardous events such as fire outbreaks, terrorist attack, etc. As mentioned earlier, a micro-simulation of network traffic flows is required to evaluate the effectiveness of such emergency readiness plans. Also, the defined road network will be useful in examining traffic operations, incident management, future planning and can also be utilized with various Intelligent Transportation System (ITS) applications

including Advanced Travel Information Systems (ATIS) and Dynamic Message Signs (DMS).

Thesis Goal and Objectives

The main goal of this research is to execute and evaluate the effectiveness of emergency readiness plans for OIA. To develop a methodology for transportation networks using WATSim in order to determine the fastest and most effective deployment strategy for the emergency response services in case of any disaster or hazard in and around the OIA areas and to examine the policies, procedures, and components that affect and are affected by emergency preparedness events.

Specific objectives of this thesis are to study the impact on OIA network due to the following events:

- Route closure and diversion due to traffic incidents
- Security checks of random vehicles
- Increased traffic on the facility

The results from these scenarios will be evaluated and invaluable information about the effectiveness of emergency readiness plans will be provided in this thesis.

Thesis Contributions

This thesis presents an approach for using traffic simulation for emergency preparedness modeling. Results from the thesis provide the OIA authority a detailed picture of how to prepare and where to deploy the emergency vehicles in case of a disaster around the OIA region. The project findings are also expected to assist Greater Orlando Aviation Authority (GOAA) transportation officials and public

safety agencies in developing effective traffic management strategies in the event of an actual regional emergency. This work will also offer them a tool to evaluate the impact of proposed actions on the transportation network operations.

Thesis Layout

The following chapters will present a review of past studies, outline of the approach, demand estimation and model validation, results and scenarios, and future scope. The literature review provides insights into the current traffic simulation models from much of the current literature and discusses the process of microscopic simulation modeling and the options available to the present day modeler. Much of the focus is on WATSim micro-simulation model, the technicalities involved with this model, review of the studies conducted using WATSim and the implications of the findings of these studies highlighted. Following the literature review, a thorough discussion of the model development approach is discussed. The chapter touches on data collection, details of model building, and preparation for calibration and validation of the model and explains the detailed procedure employed in calibration and validation. Following the model building estimation chapter, a complete discussion of how the model is calibrated and validated is presented. The final chapter provides the findings from the study conducted for the different scenarios. The conclusions and future scope of this study are then highlighted at the end.

CHAPTER TWO

LITERATURE REVIEW

Mohamed (1995), defined simulation models as “software programs that are designed to emulate the behavior of traffic transportation networks over time and space to predict system performance”. They include mathematical and logical abstraction of real-world systems implemented in software.

Traffic simulation has been applied to study a variety of traffic problems and scenarios. Besides, simulation has also provided researchers, planners and engineers with a technique to evaluate a proposed set of alternatives for a specific traffic or transportation related problem. Different traffic simulation software have been used in literature in successful application of traffic simulation. This section describes the advantages and disadvantages of using simulation.

Strengths and limitations of simulation modeling

May (1990) points out that it is important to keep simulation modeling in its context and view simulation modeling as one of several analytical techniques available to the traffic and transportation analyst. Also, he points out the following strengths of simulation modeling:

- 1) Other analytical approaches may not be appropriate.
- 2) Can experiment with new situations that do not exist today.
- 3) Time and space sequence information provided, in addition to mean and variances.
- 4) System can be studied in real time, compressed time, or expanded time.

- 5) Potentially unsafe simulation experiments can be conducted without risk to system users.
- 6) Can replicate base conditions for equitable comparison of improvement alternatives.
- 7) One can study the effects of changes on the operation of a system: “What if...happens?”
- 8) Can handle interacting queuing processes.
- 9) Demand can be varied over time and space.
- 10) Unusual arrival and service patterns can be modeled which do not follow more traditional mathematical distributions.

He emphasizes that potential reservations to simulation modeling including:

- 1) There may be easier ways to solve the problem.
- 2) Simulation can be time-consuming.
- 3) Simulation models require considerable input characteristics and data, which may be difficult or impossible to obtain.
- 4) Simulation models require verification, calibration and validation that if overlooked renders the model useless.
- 5) Some users may apply simulation models and treat them as black boxes and really do not understand what they represent or appreciate model limitations and assumptions.

With regard to traffic simulation within an ITS framework, some limitations have also been identified by The Smartest Project, (Algers et al., 1997) as follows:

- *Modeling congestion.* Most simulation models use simple car following and lane changing algorithms to determine vehicle movements. During congested conditions these do not realistically reflect driver behavior. The way congestion is modeled is often critical to the results obtained.
- *Integrated environments and common data.* Simulation models are often used with other models such as assignment models. There are common inputs required by all these models, such as origin-destination data, network topology, and bus route definitions. However, each model often requires the data in a different format so effort is wasted in re-entering data or writing conversion programs.
- *Safety evaluation.* Safety is a very complex issue. Simulation models completely ignore vulnerable road users such as cyclists or pedestrians.

Chapter 31 of the Highway Capacity Manual (2000) summarizes the strength and weakness of the simulation models as shown in table below.

Table 1. HCM interpretation of Simulation Model

Simulation Modeling Strengths
<ul style="list-style-type: none"> • Can vary demand over time and space • Can model unusual arrival and service patterns that do not follow more traditional mathematical distributions • Can experiment off-line without using on-line trial-and-error approach • Other analytical approaches may not be appropriate • Can experiment with new situations that do not exist today • Can provide time and space sequence information as well as means and variances • Can study system in real time, compressed time, or expanded time • Can conduct potentially unsafe experiments without risk to system users • Can replicate base conditions for equitable comparison of improvement alternatives • Can study the effects of changes on the operation of a system • Can handle interacting queuing processes • Can transfer un-served queued traffic from one time period to the next
Simulation Modeling Short comes
<ul style="list-style-type: none"> • There may be easier ways to solve the problem • Simulation models may require verification, calibration, and validation, which, if overlooked, make such models useless or not dependable • Development of simulation models requires knowledge in a variety of disciplines, including traffic flow theory, computer programming and operation, probability, decision making, and statistical analysis • The simulation model may be difficult for analysts to use because of lack of documentation or need for unique computer facilities • Some users may apply simulation models and not understand what they represent • Some users may apply simulation models and not know or appreciate model limitations and assumptions • Simulation models require considerable input characteristics and data, which may be difficult or impossible to obtain • Results may vary slightly each time a model is run

According to Geiger (2005), simulation can:

- 1) Enable the study of, and experimentation with, the internal interactions of a complex system, or of a subsystem within a complex
- 2) Assist in suggesting improvement in the system under investigation through using knowledge gained from the process of designing and constructing of a simulation model
- 3) Execute informational, organizational, and environmental changes, and allow the effect of these alterations on the model's behavior to be observed.
- 4) Can afford valuable insight as to which system variables are most important and how variables interact by changing simulation model inputs and observing the resulting output
- 5) Be used to experiment with new designs or policies prior to implementation so as to propose for what may happen
- 6) Can determine process and resource requirements by simulating different capabilities for a system.
- 7) Be designed for employee training to allow learning without the cost and disruption of actual on-the-job learning
- 8) Provide animation that shows a system, in simulated operation so that the proposed plan can be visualized.

Banks and Gibson, (1997), there are 10 rules when not to use simulation.

Do not simulate:

- 1) When the problem can be solved using common sense
- 2) When the problem can be solved analytically
- 3) When it is easier to perform direct experiments
- 4) When the costs exceed savings
- 5) When the resources are not available
- 6) If time is not available
- 7) If the appropriate data is not available
- 8) If verifying and validating the models will be difficult, if not impossible
- 9) If expectations are unreasonable
- 10) If the system behavior is too complex or cannot be defined

Traffic Simulation Models

Traditionally, traffic simulation models were developed independently for different facilities (e.g. freeways, urban streets, arterials, etc.). A wide variety of simulation models exist for various applications. Simulation models may be classified according to the level of detail with which they represent the system to be studied as following: Microscopic (high fidelity), Mesoscopic (mixed fidelity), and Macroscopic (low fidelity).

A microscopic model describes both the system entities and their interactions at a high level of detail. A mesoscopic model generally represents most entities at a high level of detail but describes their activities and interactions at a much lower level of detail than would a microscopic model. A macroscopic model describes entities and their activities and interactions at a low level of detail.

Another classification addresses the processes represented by the model: (i) Deterministic; and (ii) Stochastic. Deterministic models have no random variables; all entity interactions are defined by exact relationships (mathematical, statistical or logical). Stochastic models have processes, which include probability functions.

Traffic simulation models have taken many forms depending on their anticipated uses. While Federal Highway Administration (FHWA) funded the development of facility specific simulation softwares (NETSIM, ROADSIM, FRESIM, etc), these software have limited application when it comes to generalized networks with ATIS implementations. A new generation of traffic simulation models has been developed for ITS applications. Examples are AUTOS, METROPOLIS,

PARAMICS, WATSim, VISSIM, DYNASMART, DYNAMIT, INTEGRATION, THOREAU, and AIMSUN2.

Problem Solving Methods

According to Law and Kelton (2000), a system can be studied in four major ways (Figure 1):

1. Experimenting with Actual System - empirical approach:

- a) Has the highest credibility but
- b) Too expensive and almost impossible to have and check alternative scenarios

2. Experimenting with Model of System - mathematical deterministic approach:

- a) Deterministic and usually macroscopic (characteristics are averaged over time)
- b) Same answer every time
- c) Usually involves an equation or set of equations
- d) Usually involves simplifying assumption
- e) Equal arrivals of vehicles among cycles due to lack of probabilistic or stochastic nature model. Eg. uniform arrival of vehicles, within a cycle

3. Experimenting with Model of System using mathematical models - simulation:

- a) Stochastic and usually microscopic – each vehicle is treated as an object
- b) Use random numbers
- c) Have random out comes
- d) Need rules of operation
- e) Track queue accumulation and service
- f) Provide measures of performance

4. Experimenting with Model of System using Physical Model of system: This is when a physical miniature of the system is built and experimented with. Generally, unpopular and hardly practiced in the transportation industry.

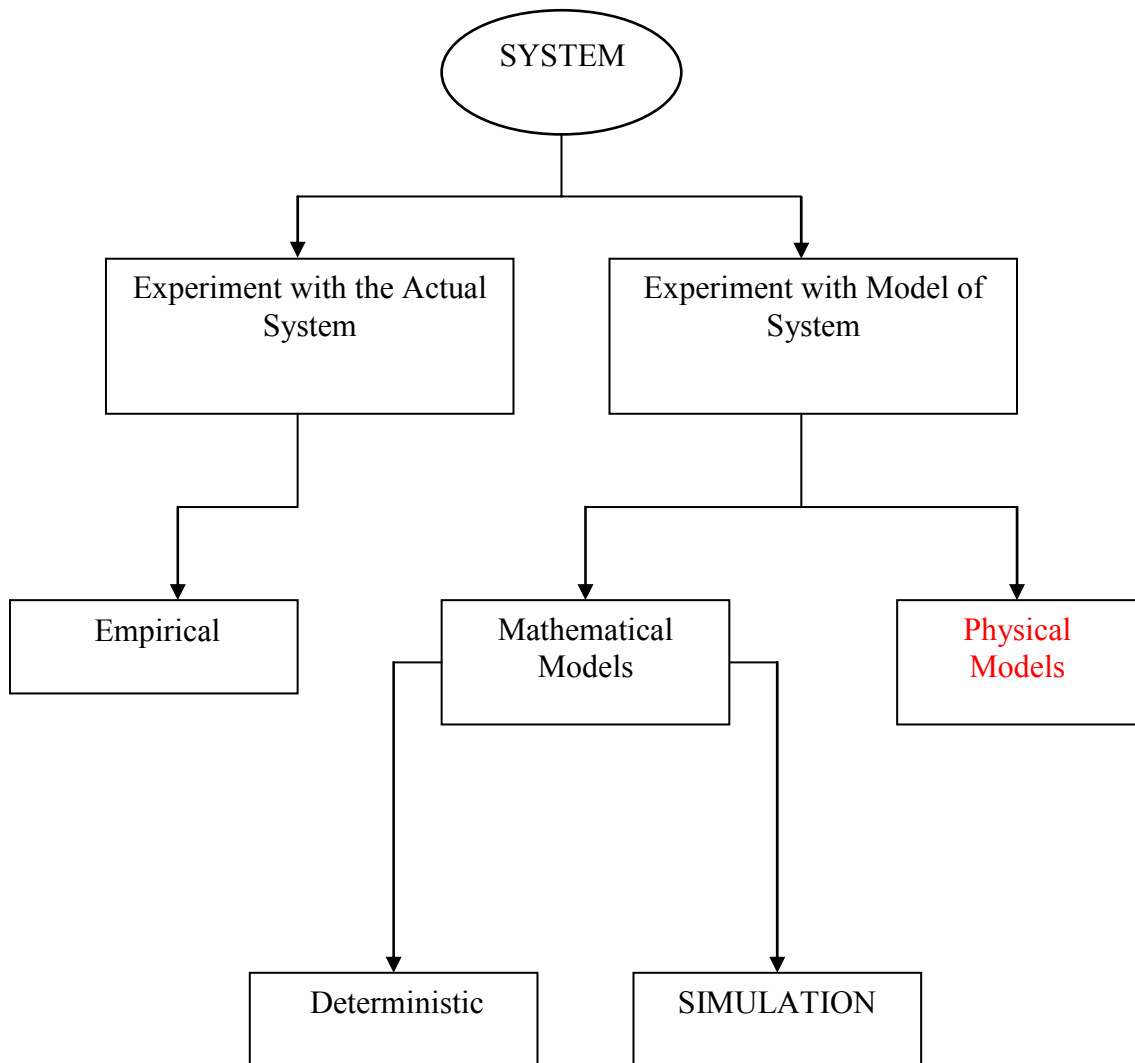


Figure 1. Problem solving methods for a system represented in a chart

(Source: Law and Kelton, 2000)

Applications of Simulation Models

Microscopic traffic simulation models have been widely accepted and applied in transportation system design, traffic operation and management alternatives evaluation for the past decades because simulation is cost effective, safe, and fast. As recognized by the Highway Capacity Manual (HCM), simulation becomes a valuable aid in assessing the system performance of traffic flows and networks. Furthermore, traffic simulation models sometimes provide significant advantages over traditional planning or analytical models such as Highway Capacity Software (HCS). For example, delay estimation from HCS is often inappropriate when the impacts of a large-scale system are considered or oversaturated conditions are prevalent (White, 2002).

Often common reasons for the popularity of simulation models include their attractive animations, stochastic variability to capture real-world traffic conditions and capabilities to model complex roadway geometries such as combined systems of urban streets and freeway.

Bloomberg et al. (2003), applied six models, WATSim, CORSIM, INTEGRATION, MITSIMLab, PARAMICS and VISSIM and to signalized intersections and freeway. The study concluded that all models performed reasonably well and were fairly consistent. The study also underscored the need for thorough and consistent calibration in simulations modeling. In all WATSim needed the least adjustment of parameters to produce reasonable results.

Korve Engineers (1996) employed the WATSim simulation model to evaluate alternative scenarios for increasing capacity and improving traffic flow on a freeway

connection, SR242 in California and ensuring a balanced design relative to freeway SR4 on the north and I-680 to the south. Design alternatives considered for three future periods (years 2000, 2010, 2020) included geometric changes, widening, HOV lanes and ramp metering. This study illustrated the use of simulation as an element of the design process with the capability of analyzing candidate designs of large-scale highway systems in a manner that lied beyond the capabilities of a straight-forward HCM analysis.

Wang and Prevedouros (1998) presented comparisons of application of INTEGRATION, TSIS/CORSIM, and WATSim using three small networks in Honolulu for which detailed and simultaneous flow conditions were known from surveillance tapes. The models produced reasonable and comparable results on most of the tested road network links. The results showed that WATSim was good at replicating true outputs.

Lieberman et al. (1996), WATSim can be interfaced with Dynamic Traffic Assignment (DTA) algorithms to simulate Advanced Traveler Information Systems (ATIS) and ITS systems. The model automatically creates Origin-Destination (O-D) tables from standard vehicle turn movements on intersections' approaches, and creates paths for traffic traveling between each O-D pair, consistent with observed traffic movements.

Skabardonis et al. (1997), described enhancements to the WATSim model to simulate vehicles with route guidance/information systems, and interface with dynamic traffic assignment (DTA) algorithms. The extended model was able to generate origin-destination (O-D) and path matrices from observed turning movement

counts, and provided comprehensive statistical, graphical and animation outputs of the vehicle movements. When applied to the San Francisco Embarcadero road network, results demonstrated that it can be used to evaluate the effectiveness of ATMIS and ITS strategies.

WATSim again, was used as the test-bed for the evaluation of the DTA concept. KLD in 1997, performed this task for the California PATH program of the ITS Center for Excellence at the University of California at Berkeley.

Figure 2 shows the view of San Francisco from KLD's WATSim simulation model showing an optimal routing pattern (in blue). During an incident along this route, a dynamic traffic assignment algorithm determines a new optimal route (in red). Vehicles equipped with ITS communications are informed of this new route.

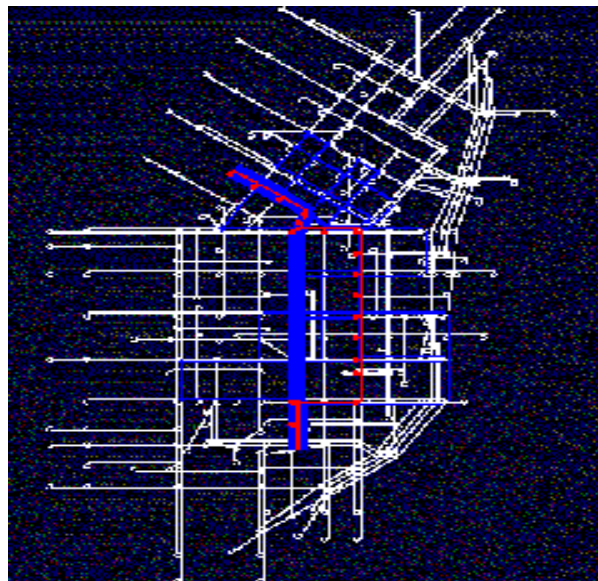


Figure 2. WATSim ITS Application to San Francisco Embarcadero road network

(Source: <http://www.kldassociates.com/its.htm>, URL Accessed on October 2005)

Wang, and Prevedouros (1997) applied INTEGRATION, TSIS/CORSIM, and WATSim models to three heavily loaded traffic networks for which exact volumes and speeds (on specific lanes and locations) were known. The models produced reasonable and comparable simulated results on most of the tested network links. The experiments also revealed that the main limitation of these models is the large number of parameters that need to be modified in order to replicate the real traffic conditions. In no case did the default parameters offer satisfactory results. In all, WATSim required the least modification to default parameters to achieve good results.

KLD Associates has successfully and extensively applied its WATSim traffic simulation model in projects across the United States and overseas. Selected applications include, Proposed COSTCO Gas Station - Issaquah, WA, Proposed Improvements to St. John's Rotary in Manhattan – Port Authority of NY & NJ.

In 2001, the North Atlantic Energy Service Corporation engaged KLD Associates and provided evacuation time estimate for the Seabrook Nuclear Power Station.

Goldblatt and Horn (1999) used WATSim simulation to evaluate traffic Signal preemption at Railway-Highway Grade Crossings

Lieberman (1996) applied WATSim for the Preliminary Designs of Conventional and Dispersed Movement Intersections at MD route 175 and Dobbin Road, Howard County,

Goldblatt (2000) applied WATSim to Parking Cashier Plaza Simulation Analysis for Several Proposed Designs. He again in (1997, 1996) applied WATSim

for the Development of Evacuation Time Estimates for the Pine Bluff Arsenal and Blue Grass Army Depot respectively. He also used WATSim in (1996) in Preparing of the Preliminary Design of a Dispersed Movement Intersection at Broken Land Parkway and Snowden River Parkway, Howard County, MD.

Mousa (2004) applied WATSim and PARAMICS models to Alafaya-University Intersection. She found out that both calibrated models (PARAMICS and WATSim) well represented the actual delay at intersection at a confidence level of 90%. While for both models the fundamental logics and the underlying models (car following, lane change, etc.) are different, the results obtained from PARAMICS and WATSim were not significantly different.

Kanike (2003) in his thesis used PARAMICS to perform traffic simulation of the road network around the vicinity of the Orlando International Airport. Fire trucks were released from 7 fire stations considered within the network. The results showed that, one fire station which is on the Shoal Creek Dr had the shortest response time of 4 minutes 11 seconds followed by the remaining fire stations. The results of his research demonstrated the potential of using traffic simulation model for emergency response modeling.

Applications like user's route choice dynamics in the case of lane closures was studied in a simulation environment by Mahmassani and Jayakrishnan (1991). The results showed that providing real time in-vehicle information to users could lead the network to reach a steady state at a faster rate than under the no-information case.

Modeling traffic flows in networks involving advanced traffic control and route guidance systems by Yang and Koutsopoulos (1996) using MITSIM

(Microscopic Traffic SIMulator) on the A10 beltway in Amsterdam, the Netherlands network with non-recurrent congestion caused by a 20-minute incident, the case study demonstrated that on average 2-4% of travel time savings is achieved when real-time traffic information is provided to 30% of drivers. For drivers having viable alternative routes, real time route guidance is very effective, creating travel time saving of up to 18%.

Al-Deek et al. (1988) discussed a study on the I-10 corridor project using FREQ8 model simulation to evaluate the benefits of In-vehicle Information Systems (IVIS). In this study the FREQ model was used to simulate a section of the Santa Monica I-10 freeway in California. The study estimated delays, queues and travel times on the freeway based on scenarios of recurring and incident congestion.

Shaw and Nam (2002) concluded that in an integrated project selection process, output data from micro simulation could serve as input for engineering economic analysis, which in turn provides an objective basis for selection of projects implementing the freeway reconstruction. The context was the Southeast Wisconsin Freeway System Operational Assessment (FSOA), a detailed examination of the safety and operational performance of the Metropolitan Milwaukee freeway system. As the project and software technology evolved, micro simulation emerged as the basis of an ongoing process for analyzing system wide freeway operations.

Cheu et al. (2002) used PARAMICS to simulate different incident scenarios and used results from the simulation output to test the algorithms for incident detection.

Lee et al. (2003) applied PARAMICS to explore the potential employment of real-time information for the efficient management of city logistics operations. Simulation results suggested that the diversion strategies examined usually resulted in reduced travel times, which improved the efficiency of commercial vehicle operations (CVO).

Abou-Senna (2003) applied PARAMICS to analyze dynamic routing decisions in the Central Florida limited access network comprising the I-4 and the toll roads (SR417, SR408, SR528) in response to real time information through various stochastic assignment methodologies.

Ramasamy (2002) developed a microscopic model to study the traffic characteristics on the University of Central Florida campus using PARAMICS. One of his detailed scenarios analyses was done at the Gemini Blvd. East and Orion Dr. intersection. He concluded that having the Gemini circle as 4 lanes and a signal at the Gemini Blvd. East and Orion Dr. intersection, most of the traffic problems inside the campus could be eliminated. His work and conclusions demonstrated the potential of using simulation in solving traffic related problems.

Shaaban (2005) in his PhD dissertation used SimTraffic to investigate the types of weaving movements occurring between two closed-spaced intersections on an arterial street. He proposed a new concept, Right Turn Splits (RTS) to alleviate the operational and safety problems caused by weaving movements on arterial streets. His findings showed that, for the geometric and volume conditions tested, the proposed concept provided lower delay on the arterial streets than the original

conditions, which concluded that the RTS concept not only provided a safer environment on the arterial street but also provided a delay reduction.

Evaluation of Simulation Tools

According to recent studies, there are more than 70 simulation models available. With all these models, it is hard to select one of them to use. From the evaluation done by Skabardonis (1999), five of these models were found to satisfy the majority of the evaluation criteria: CORFLO, CORSIM, INTEGRATION, PARAMICS and WATSim.

Although there are no specific references reviewed documenting the comparison of WATSIM with other leading simulation software, numerous researchers, Steven et al. (2004) have compared various capabilities of traffic simulation packages in past efforts.

A summary of key comparisons by Steve et al. (2004) and Mousa (2004) is presented in the Tables 2 and 3. The purpose of the review was not to summarize all work in this area, but rather to present representative findings relevant to the current study.

Table 2. Summary of previous traffic simulation comparisons
(source: Steve et al. 2004)

Reference	Packages Compared	Key Findings
Middelton and Cooner, 1999	CORSIM (FRESIM component), FREQ and INTEGRATION	Models were used to simulate congested freeway conditions. All models performed relatively well for uncontested conditions. They were all, however, inconsistent in their ability to accurately model congested conditions.
Bloomberg and Dale, 2000	CORSIM and VISSIM	Models compared for congested arterials. Found models produced consistent results among them. Also cited that both equally user friendly with respect to initial coding. Paper stressed need to understand how models work and compute performance measures.
Boxill and Yu, 2000	CORSIM, INTERGRATION, AIMSUN and PARAMICS	Models were evaluated on their ability to simulate ITS. Study concluded that AIMSUN and PARAMICS have significant potential for modeling ITS but require more calibration and validation for the U.S. CORSIM and INTERGRATION were concluded to be the most probable for ITS applications due to familiarity and extensive calibration/validation.
Barrios et al., 2001	CORSIM, VISSIM, PARAMICS and SimTraffic	Packages were evaluated based on their graphical presentation (animation) capabilities. In particular, the selected package was to be used to simulate bus operations. A review of transit-related and visualization capabilities of each model is presented. Ultimately, VISSIM was selected due to its 3-D capabilities.
Trueblood, 2001	CORSIM and SimTraffic	Results showed little difference between models for arterials with low to moderate traffic. Paper stressed importance of user familiarity with models and need to properly validate.
Choa et al., 2002	CORSIM, , PARAMICS and VISSIM	Ability of models to accurately simulate a freeway interchange is compared. Study concluded that CORSIM was the easiest to code. Cited link-based routing in CORSIM and POARAMICS as a source of potential inaccuracy in modeling closely spaced intersections. VISSIM uses route-based routing that eliminates problems associated with link-based. Ability of CORSIM to compute control delay for individual approaches was cited as an advantage. "Artificial barrier" between surface streets and freeways in CORSIM cited a source of inaccuracies. PARAMICS and VISSIM were determined to more closely reflect actual conditions. 3-D capabilities of PARAMICS and VISSIM cited as an advantage.
Demmers et al., 2002	CORSIM and SimTraffic	Model results compared for congested arterial conditions. Models produced different results for the same arterial.
Kaskeo, 2002	VISSIM, CORSIM and SimTraffic	Simulations were conducted and compared for three facility types: freeways, interchanges, and arterials with coordinated signals. Stated that CORSIM was the most mature and widely used package. Study found that VISSIM was most powerful and versatile (e.g., roundabout, LRT, and pedestrian capabilities). Study found VISSIM the least user friendly and cited additional effort and post-processing to make use of outputs. SimTraffic was found to be the most straightforward to use.
Tian et al., 2002	CORSIM , SimTraffic and VISSIM	Signalized arterials were studied. Results indicate that outputs varied with link length and speed range in addition to volume levels. In general outputs varied more as volume approached capacity. CORSIM displayed less overall variability than SimTraffic.
Bloomberg et al., 2003	CORSIM, INTEGRATION, MITSIMLab, PARAMICS, VISSIM and WATSIM	All six models were applied to signalized intersections and freeways. Study concluded that all models performed reasonably well and were fairly consistent. The study underscored the need for thorough and consistent calibration in simulations modeling.

Table 3. Evaluation of PARAMICS and WATSim capabilities based on their ability in simulating real traffic conditions
(Source: Mousa, 2004)

		PARAMICS	WATSIM
Data Input	Node Coordinate	√	√
	Link length	√	√
	# Lane/usage	√	√
	# Type pockets		√
	Turning Movements		√
	Vehicle occupancy		√
	O-D data	√	
Control	Detectors	√	√
	Fixed Time Signals	√	√
	Actuated Signals		√
Characteristics	Variable Time Steps	√	
	Vehicle length considered in gap logic	√	NI
	Variable headway	√	√
	Variable driver reaction time	√	NI
	Variable Acceleration/Deceleration	√	√
	Variable queue discharge headway	√	√
	Sight distance limits		NI
Capability of Modeling	Restricted lane	√	√
	Exclusive lane (bus/car pool)	√	√
	Incident	√	√
	U-turn movement		
	Toll plaza	√	√
	Pedestrians		√
	Work zone	√	√
	Roundabout	√	NI
	Emission analysis	√	√
ITS Feature Modeled	Driver behavior	√	√
	Vehicle interaction	√	√
	Congestion pricing	√	√
	Queue spill back	√	√
	Ramp metering	√	√
	Route choice/update	√	NI
	Transit signal priority – exclusive lane	√	NI
	Transit signal priority – mixed traffic	√	NI
Relation to Highway Capacity Manual			√
Outputs	Statistics	√	√
	2-D Animation	√	√
	3-D Animation	√	XE
More Friendliness			√

LEGEND:

NI: No information available

F: Future model enhancement

XE: External program

Weaknesses

Steven et al. (2005) concluded, WATSim has a limited capability to assess ITS technologies such as route guidance systems/VMS though not a major concern in this study. It also does not provide 3-D graphical output readily, hence it is not that much attractive as other simulation models such as VISSIM and PARAMICS, which have superior graphical outputs. Since WATSim generates link-based outputs, it is difficult to obtain certain route-based measures or individual measures such as travel time unless a crude way is engaged. More specifically, computer simulation studies of highway traffic are most commonly carried out using various commercially available microscopic simulation packages, such as WATSim, NETSIM and VISSIM, which are all PC Windows-based, and are thus limited to the computational power available on standard PCs. This memory constraint combined with the high computational requirements of microscopic simulation results in test scenarios that are typically limited to small networks of around 15 intersections. Complete trips cannot be modeled on networks of this size, so generation of traffic is left to intersection turning movement counts.

This turning movement-based approach ignores vehicle route changing behavior that results in reaction to the change in traffic conditions. Specifically, it is reasonable to assume that deployment of certain ITS schemes will change the traffic pattern thus changing travel times not only for the vehicles affected directly, but also of regular vehicles traveling both along and across the corridor. As a result, vehicles may choose to use or not to use their existing path depending on whether or not their approach is given the advantage, and may therefore change their travel route.

However, the turning movement-based approach takes intersection traffic volumes and splits as an input parameter, thus assuming that the flows and turning movements on the corridor remain unchanged regardless of any shift in travel time advantage.

Summary

The first part of the literature review presented in this chapter provides some basic background information about the traffic simulation and the issues related to the simulation. This part of the chapter gives an idea and description of some popular simulation models available on the market and their capabilities with respect to the size of road network, limitations and ITS.

The second part provides the background of the WATSim micro-simulator and the studies related to the use of WATSim simulation model. The findings from the literature review can be summarized as follows:

- Give an insight of the capabilities of WATSim
- Explain in detail about the problems associated with WATSim

After the thorough literature review, there was only limited research at this time regarding the use of WATSim microscopic traffic simulation on modeling emergency preparedness plans of airports. Thus, this study utilizes the capabilities of WATSim to develop an emergency preparedness plans model for Orlando International Airport. The literature also showed that WATSim would be a good and valid tool to use in achieving the objectives and goals of this study.

CHAPTER THREE

METHODOLOGY

The methodology is an application of a micro simulation model (WATSim) to simulate a limited network of the OIA area on the microscopic level. The developed research approach and methodology consists of the following steps:

- a) *Knowledge Acquisition and Data Manipulation:* First task of this research involved the attainment and manipulation of traffic data in the OIA area and its immediate surroundings. Data were obtained from GOAA, Central Florida Expressway Authority, Orange and Osceola Counties Department of Transportation, City of Orlando and from other relevant sources
- b) *Model Development:* Second task involved building an appropriate WATSim model for the OIA area network, which entails obtaining the most accurate map for the region, and identifying key routes. This phase included the identification of the various elements of the transportation network, including nodes, parking lots/garages and links.
- c) *Network Coding.* Code and outline a base network for the micro-simulation model of the OIA area including some major highways and primary arterials. The relevant geometric and traffic signal timing was also included.
- d) *Model Calibration.* Finalized the defined road network model and conducted several runs for the design hourly volume (DHV). These runs are used to conclude the best traffic parameter that provides minimum error between the

simulated outputs and field data, which includes traffic volumes that will be used to compare link counts between the simulated and actual values.

The procedure for calibration and validation of the OIA WATSim Network includes three major steps:

1. Visual observations
2. Adjustment of WATSim parameters eg., (Vehicle queue discharge headway, Gap, Lane switching lag, Saturation flow rate etc.)
3. *Model Validation.* The model must be validated in order to assure that it can replicate the actual or local system. This will be accomplished by mainly comparing observed and modeled traffic counts. The comparison will also be verified visually as well as conducting a t-test.

e) *Experimentation.* The fifth task involved experimenting with various scenarios under a variety of conditions:

- Traffic incident and alternate route / Diversions
- Security check
- Loading network to exceed capacity to find where and when the network breaks down

For example, incidents will be simulated by placing traffic logic controls on a lane or a group of lanes during a specified time and duration. Model will run using these conditions and the average queue length of vehicles, the travel times to terminals A and B and overall network performance determined.

f) *Conclusions.* Results were interpreted to establish findings and make recommendations for preparedness plan, future research and analysis for OIA.

CHAPTER FOUR

MICROSCOPIC SIMULATOR - WATSim

Overview

WATSim (Wide Area Traffic Simulation) is a microscopic model developed by KLD Associates Inc. in 1996. It is based on the TRAF-NETSIM simulation model, extended to simulate traffic operations on freeways and other roadways of any configuration. It incorporates an improved lane changing and car-following logic to represent stochastic driver behavior, and freeway links with differing capacities associated with different grades, lane widths and horizontal curvature (KLD, 2001).

KLD Associates Inc. (KLD) is an organization of transportation engineers and computer scientists with expertise in the development and application of computerized tools to solve complex transportation problems, including the development of emergency evacuation plans. It is also one of the foremost organizations in the United States in the development of computer simulation models in support of traffic, transit and transportation planning activities. KLD Associates was responsible for many of the standard computer simulation models used in the industry including most of the traffic simulation models sponsored by the US Federal Highway Administration (FHWA).

WATSim is run within a software environment called the Unified Integrator of Transportation Engineering Software (UNITES), which provides an integrated, user-friendly Windows-based interface and environment for executing WATSim (KLD, 1996). It has the capability to represent any combination of freeways, ramps,

interchanges and surface streets. It can differentiate between freeway and surface street links and automatically applies car-following and lane-changing logic appropriate to each environment.

WATSim is able to simulate detailed vehicle-specific traffic processes so that actuated signal control and dynamic routing may be simulated, and vehicle-to-vehicle and vehicle-to-control device interactions may be explicitly modeled. In addition, the pedestrian traffic can be modeled. The user can examine the outputs of WATSim with color displays, which provide details of intersection geometrics or highlight potential hot spots or problem areas in the network. It is also able to provide a 3-D animation of simulated vehicle movements.

WATSim's operational features include those in TRAF-NETSIM plus HOV configurations, light rail vehicles, toll plazas, path tracing, ramp metering, and real time simulation and animation. The WATSim simulation model also includes an interface with a traffic assignment model.

TRAF-NETSIM was selected as the basis for the development of WATSim since NETSIM has had 25 years of continuous support and development sponsored by the FHWA. TRAF-NETSIM[®] has become FHWA's most popular traffic simulation model for urban traffic. It has been extensively validated and used by hundreds of agencies worldwide. As a result of the extensions, WATSim can model any combination of freeways, ramps, interchanges, surface streets and toll plazas. The consistent modeling approach for each traffic environment (all based upon the long lived and well tested TRAF-NETSIM) is a unique characteristic of WATSim.

The model can also be interfaced with Dynamic Traffic Assignment (DTA) algorithms to simulate ATIS and ITS systems. It is not marketed as stand-alone software but it is offered as part of a contract with its developer. WATSim has been tested and is currently in use in real world applications (Steven et al. 2004, 2005). However, the academic version used for this research does not come with any ITS functionalities.

WATSim accommodates path assignments computed by a DTA model for different vehicle classes. The model produces link travel times and other statistics needed by a DTA model to compute minimum travel time paths for each O-D pair. Recent extensions to WATSim include simulation of light-rail preemption algorithms, toll plaza operations, and linkages with the TRANSYT-7F and PASSER-II signal optimization programs to optimize the signal settings along arterials and networks.

WATSim Operating Characteristics and Features

WATSim is a time-scanning simulation model. Each vehicle in the traffic stream is represented as a distinct entity which is "moved" once each second accounting for the current traffic conditions. Vehicle trajectories are computed according to car-following logic which responds to the performance of neighboring vehicles, traffic control devices, and other conditions which influence driver behavior. These responses reflect both the performance capabilities of the individual vehicle and the relative "aggressiveness" or "timidity" of the simulated motorist. Each vehicle is assigned a driver with specific behavioral characteristics to perform driver decisions including lane selection and lane changing. Each vehicle also is identified by category (car, car-pool, bus, truck etc). For example, car-pools and buses may be

restricted to specific lanes. An individual vehicle is further characterized by type of car, bus, etc. reflecting specific operational and performance characteristics. A fleet of up to 16 different "types" of vehicles can be specified by the user.

The output of the model includes a variety of measures of effectiveness describing traffic operational performance. These include speed, volume, delay, spillback, and queues. Fuel consumption and pollutant emission measures are also provided. Traffic performance measures are available for each network link, each intersection, groups of links and the entire network over user-specified time intervals. Measures of effectiveness for a toll plaza can be provided on a per-lane basis while measures of transit operations are available by route and station (KLD, 2001).

Animation Displays

An affiliated interactive computer graphics program provides an on-screen 2-D animated display of simulated traffic operations. The aerial view animation display clearly depicts individual vehicle movements. Any animation frame can be printed and included within written reports.

As an option, KLD Associates can also create 2-D or life-like 3-D animations of simulated traffic operations on video tape. The 3-D animations at varying levels of realism and background detail help to match project needs and budget.

WATSim also interacts with a statistical analysis package to produce an animated 3-D bar chart display of changes in speed and roadway density over distance and time. Any combination of traffic performance measures of effectiveness can be displayed in this fashion.

How large an area can be simulated with WATSim?

To date, WATSim has been employed to model large portions of:

- The West side of Manhattan
- Downtown San Francisco
- Downtown Los Angeles
- A 20 mile corridor in Contra Costa County, California including numerous interchanges and adjacent streets.

The model is currently sized to represent roadway systems of up to 1800 links with 125 bus routes, 300 transit stations and 20,000 vehicle movements per second including 3,000 bus movements per second. However, for the academic version, there is a limitation on the size of the Network (500 links), number of nodes (200), and number of vehicles (30,000). Given the low cost and availability of Random Access Memory, the model can be easily adjusted by KLD Associates to represent larger roadway systems as needed (KLD, 2005).

Input Data Requirements

Traffic demands for WATSim models are specified in terms of turning fractions at the network nodes per time period, and (optionally) origin-destination (O-D) data if traffic assignment is executed at the start of the simulation.

Traffic control data include specifications of the control type (traffic signals/stop signs, pedestrian signal) as well as type of traffic signal, phasing, phase length, offsets, detector type and location. WATSim can model in detail actuated controller operations and require data on several control parameters.

Traffic Generation and Assignment

WATSim uses the turning movement data specified to allocate and transfer the appropriate flow from one link to another in the course of simulation. The turn specifications on this record are presented in the form of either the percentage of vehicles performing each movement at the downstream node of the subject link or are expressed consistently in terms of the total number of vehicles per hour performing the movements. These percentages or hourly volumes are applied over the duration of one Time Period. For subsequent Time Periods, it is optional and need only be used to specify changes in turning specifications. Inputs for any time period remain in effect until they are changed.

If the turn specifications are presented in the form of vehicles/hour, the model will internally convert these inputs to turn percentages. If any one entry contains a percentage, then all must; similarly, if one entry contains a vehicle count, then all must. WATSim applies these turn specifications to all components of the traffic stream (i.e., autos, trucks, car pools) except buses. Turn decisions for buses are based upon the route information specified. Under these conditions, buses should be excluded from the turn counts or percentages specified. (practically speaking, unless bus traffic is heavy, the inclusion or exclusion of buses will have little effect on these inputs.)

Traffic volumes may be entered in terms of vehicle counts for certain time period or flow rates for up to 19 time periods.

The WATSim model can generate headways stochastically using either a normal, shifted exponential or Erlang distribution.

The form of the Erlang distribution is:

Equation 1:

$$f(t) = \frac{(qa)^a}{(a-1)!} t^{a-1} e^{-aqt} \quad a = 1, 2, \dots$$

The variable, a , describes the level of randomness of the distribution ranging from $a=1$ (most randomness) to $a=4$, (complete uniformity). The case where $a=1$, is the negative exponential distribution.

The model can emit vehicles from entry links and source points at a uniform (fixed) rate or a variable rate. The headway may be varied between each emission. A random number seed is used to generate a random variation for each emission headway. The seed may be varied between runs to vary the times that vehicles are scheduled to enter the simulated roadways. The total number of vehicles due to be emitted will remain the same between runs even though the time between individual vehicle emissions will vary.

The routing logic of WATSim is based on link-based turning movement volumes or percentages. WATSim, also deploys a traffic assignment techniques with equilibrium and optimization capabilities (WATSim User Guide, 1996).

Traffic Control

WATSim can model yield signs, stop signs, and traffic signals. It provides a user friendly interface for editing UNified Integrator of Transportation Engineering Software (UNITES), pre-timed, actuated, and pedestrian control properties and is capable of simulating pre-timed and actuated signals. In this research, the basic version of WATSim was used therefore has limited functionalities.

Multi-Modal Transportation

Traffic stream may consist of 9 different types of vehicles having various operating and performance characteristics. The default four different fleet components include passenger car, truck, bus and car pool, consisting of several default vehicle types. The user can specify any vehicle type with specific performance characteristics if he or she is not satisfied with the default values for vehicles (WATSim User Guide, 1996).

Measure of Effectiveness (MoE)

WATSim provides a variety of numerical MoE's, which can be link specific, aggregate for multiple links or network wide. The main MoEs that WATSim provides include vehicle trips, vehicle miles, travel time, delay time, including queue delay, control delay and total delay, and occupancy.

UNITES Overview

As aforementioned, WATSIM is run within a software environment called the Unified Integrator of Transportation Engineering Software (UNITES), which provides an integrated, user-friendly Windows-based interface and environment for executing WATSim (KLD, 1996).

UNITES is comprised of the following components:

- 1) A generic graphical user interface (GUI), named the "UNITES Network Editor" (UNET) supports the data needs of the models in the UNITES "toolkit".

- 2) A database management system (DBMS) that performs the storage, formatting and manipulation of data that resides in a central database that is application independent.
- 3) A separate Model Interface Program (MIP) designed for each Legacy Traffic model supported by UNITES. The MIP performs the functions which:
 - “Marshalls” the data stored within the database that are needed by the model to form the input file, then “launches” the execution of the model.
 - Retrieves the data that are output by the model and stores them into the central database.
- 4) The suite of supported models.
- 5) Interface with MS Office and with other “third-party” software products through widely accepted database standards.
- 6) The supported models may be maintained by the individual vendors. Most model updates would not affect the UNITES software.

Figure 3 shows the open architecture of the UNITES. It supports the continuing evolution of UNITES over time.

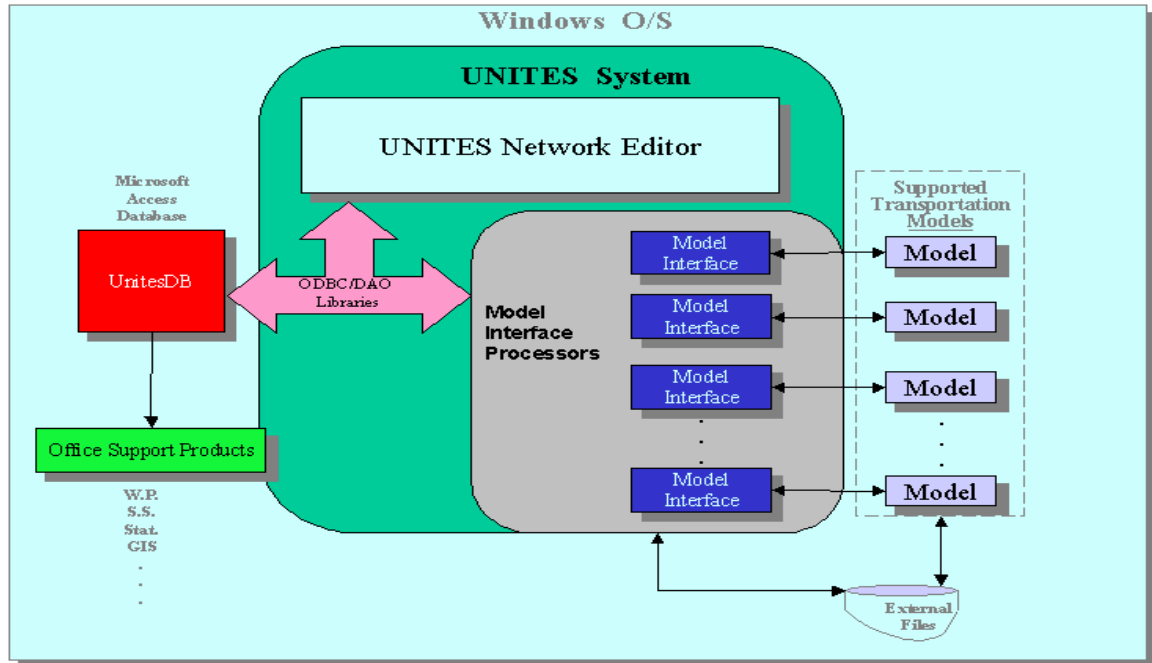


Figure 3. Unites Architecture

(Source: KLD Associates Inc, UNITES User Manual, 1996)

UNITES Network Editor

The UNITES Network Editor (UNET) provides an interactive data-entry environment for the user to create and edit traffic network specifications. It also provides the means for the user to “launch” the various traffic models supported by UNITES and greatly enhances the user’s ability to analyze the results. This software automatically creates the input streams required by the models. The user has one common interface which supports all of the UNITES traffic models.

Specific WATSim Network MoEs

Network MoE for All Networks

This will create a spreadsheet with all Network based MoE for all networks that contain such data.

Link MoE for All Networks

This will create a spreadsheet with all Link based MoE for all networks that contain such data.

Link MoE for This Network

This will create a spreadsheet with all Link based MoE for the current network if it has such data.

Vehicle Type Specification

This allows the user to define the characteristics of the network vehicle fleet. Up to sixteen different vehicle types may be specified. The specifications include Vehicle Length, the maximum acceleration rate, the maximum speed, the percent of mean queue discharge headway specified for each link that is required by the vehicle, the percent of the automobiles represented by this vehicle type, the percent of trucks represented by this vehicle type, the percent of buses represented by this vehicle type, the percent of car-pools (HOV) represented by this vehicle type, and the average number of persons carried by the vehicle type. It also provides for a short vehicle description. Finally, a proportion of each vehicle type can be added to the probe vehicle fleet.

Statistics

When a model is executed, it generates output data. The Model Interface Processors (MIP's) read the model's output text files and store these output data in the UNITES central database. UNITES makes these data available to external (i.e., not part of the UNITES system) office software via its Access-based database. Any product that has an ODBC (Open Database Connectivity) interface should be able to read UNITES data.

Additionally, UNITES provides a graphical display of selected link-specific statistical Measures of Effectiveness (MoE) on its link-node schematic diagram. Users can view the spatial distribution of operational performance MoE over their network. This menu item has four choices: Display MoE; Color; Thickness and Legend.

CHAPTER FIVE

ORLANDO INTERNATIONAL AIRPORT (OIA)

Introduction

Orlando International Airport (MCO) is a major gateway to Florida - over 80,000 passengers use this airport every day. It features a main terminal, which is connected to four airside terminals. Each airside terminal serves several airlines and a large number of destinations. The main terminal has two parts, the north Side A and the south Side B (OIA, 2005).

It is easily accessible from all major Florida cities and has extensive facilities such as parking, and ground transportation options.

The OIA Road Network Description

Orlando International Airport is located nine miles southeast of downtown Orlando, at the junction of State Road 436 (Semoran Boulevard) and State Road 528 (Beeline Expressway).

As shown in Figure 4, OIA is accessed from two main directions: north access which is immediately connected to State Road (SR) 436 (Semoran Blvd) and SR528 (Bee Line Expressway), and in the south; South Access to SR417 (Central Florida Greenway). Most of the links are arterials with some state roads that have high capacity due to their geometric features. Several other roadways are in the vicinity of the airport and when combined with the aforementioned three highways form the highway/street network around the airport. These include SR15, Trade port drive, and

Boggy Creek road. While SR436, SR528, and SR417 provide direct access to the airport, one cannot study the roadway network around the airport, particularly in the case of closures/emergency, without addressing the other surrounding routes as well.

While the resulting model will involve limited OIA region, the methodology and approach could be executable to other areas. The model was based on historical peak traffic levels during various times of the day and includes the functionality of updating the routes to various traffic congestion levels. The research team contacted the Greater Orlando Aviation Authority (GOAA), Orange and Osceola Counties traffic engineering departments and City of Orlando to obtain the necessary data to validate the developed model. The data include, but not limited to, the roadways' traffic volumes, Average Daily Traffic (ADT), Signal control types and Phasing Plans.

Figure 4 shows an aerial map of the study area. Trips were made to the selected OIA area to investigate the defined network. All nodes were checked to determine if there were significant changes in the geometric features on the links from the field inspection.



Figure 4.OIA Aerial View of study area

(Source: <http://terraserver-usa.com>. URL Accessed on May 2005)

OIA Road Network Data Collection

The required data for coding, calibrating, and validating the OIA model were:

- Geometric features
- Turning movements/counts at each intersection and/or interchange
- Type of control at an intersection

The City of Orlando provided signal-timing data (Appendix A and B) for the 3 coded signalized intersections (1. Semoran Blvd and Lee Vista Blvd., 2. Semoran Blvd. and Hazeltine National Dr., 3. Semoran Blvd and T.G Lee Blvd/Frontage Rd.). Geometric features of the network and control data type for all network locations were not available. The missing information about the network geometry and type of control at intersections of the network was obtained during field trips to the OIA's surrounding road network. GOAA was contacted to obtain any available data on counts for the OIA internal network links and its surroundings. A soft copy of relevant data records including the Average Daily Traffic (ADT) was obtained from GOAA. Most of the link volume data were collected by GOAA in the Easter holiday peak period of 2004, although not all locations were covered and older inventory data had to be used. The K factor that is the ratio between the peak hour volume and the daily volume was set to 8% and percent of vehicle splits at intersections were computed manually.

OIA Model Development

Model Development Cycle

The OIA network was coded into WATSim and processed by the following steps in Figure 5:

1. Importing OIA network in AutoCAD dxf file format into UNITES (front end)
2. Building a road network by adding nodes, links and zones and coding detailed lane and junction descriptions.
3. Assigning traffic using an appropriate assignment technique.
4. Collecting and analyzing model results.
5. Calibrating and validating base model by comparing model results to observed/field data.

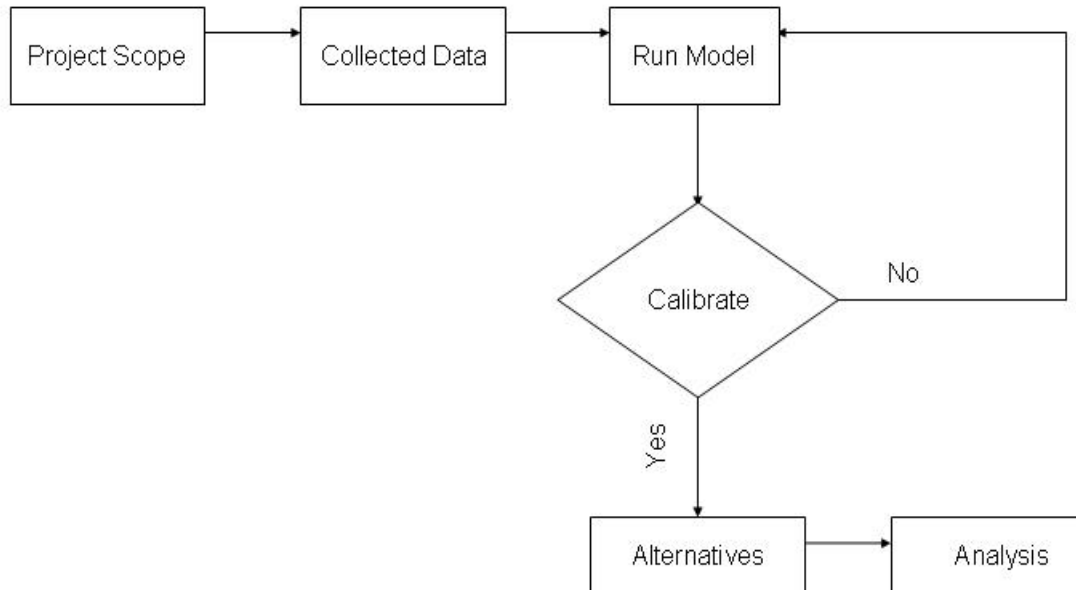


Figure 5. Typical Simulation Steps

OIA WATSim Model Dataset Coding

CAD drawing, GIS files were utilized to develop the OIA network. After importing the template road geometry file (AutoCAD dxf file) – Figure 6, the road network is then built by adding nodes, links and coding detailed lane, junction descriptions and circulating traffic at sides A and B. A node is defined as an intersection or an interchange and links are the road segments that connect any two nodes

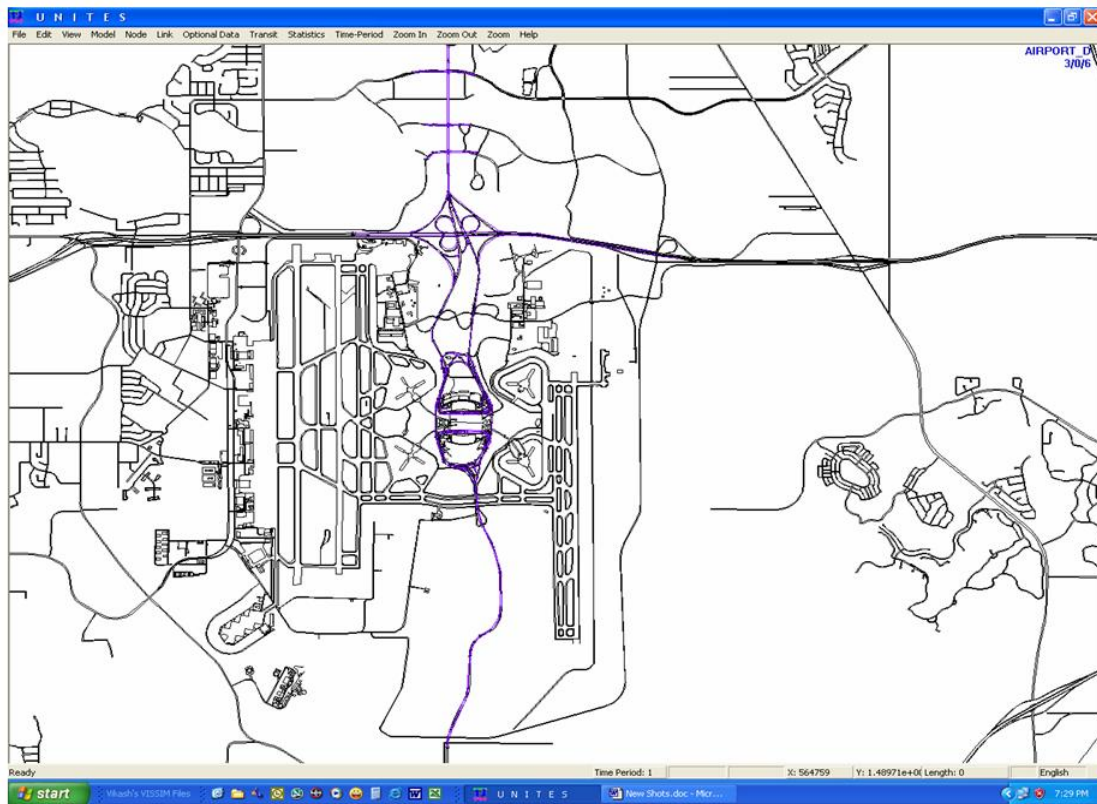


Figure 6. Background DXF File of OIA Area network in the UNITES Editing Window

Signal Control Coding

The 3 signals at 1. Semoran Blvd and Lee Vista Blvd., 2. Semoran Blvd. and Hazeltine National Dr., 3. Semoran Blvd and T.G Lee Blvd/Frontage Rd. intersections were coded and simulated as pre-timed signals and justified based on the fact that both major and minor roads were considered near capacity during the peak period hours.

Each of this signals were coded as four phases with cycle lengths of 130 seconds at intersections (1. Semoran Blvd and Lee Vista Blvd., 2. Semoran Blvd. and Hazeltine National Dr). and 120 seconds at (3. Semoran Blvd and T.G Lee Blvd/Frontage Rd.). The cycle lengths coded were derived from the actuated control signal timings shown in appendixes A and B.

UNITES uses the DXF drawing image or bitmap files as a background overlay for entering traffic network. Nodes and links were coded on the background DXF file of the network as shown in Figure 7:

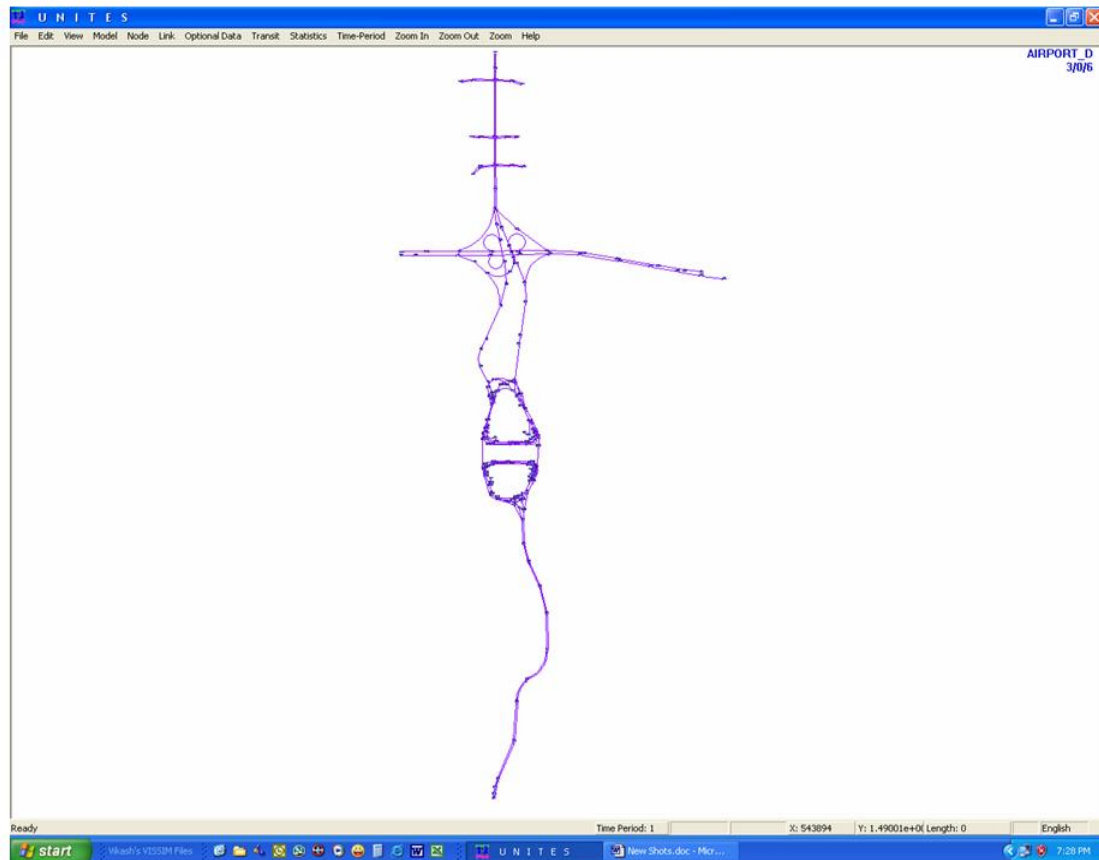


Figure 7. Base Network of OIA showing Nodes and Links

Coding of Re-circulating Volume

Table 4 shows the summary statistic of the peak hour re-circulating volume for terminals A and B. To determine the volume and percentage of re-circulating traffic accurately, license tag data was collected at the exits of the arrivals curbs, with tags passing through the curb area multiple times being matched and quantified (GOAA, 2004). The total arrival curb volume for Side A is 736 vehicles and that of Side B 356 vehicles. There are a total of 315 and 131 re-circulatory trips made to terminals A and B respectively. On the average, a vehicle makes 2.0 to 2.6 trips.

Table 4. Peak Hour Re-circulatory Volume Analysis Summary

	SUMMARY STATISTICS	
	A-SIDE	B-SIDE
Total Curb Volume (from video)	736	356
Percent of Counts Used	100.0%	99.4%
Total Re-circulatory Trips	315	131
Percent Re-circulating Trips	42.8%	36.8%
Maximum No. of Re-circulating Trips	27	11
Average No. of Re-circulating Trips	2.0	2.6
Total Re-circulating Vehicles	160	51

(Source: GOAA Easter Peak Season Daily Traffic Counts, 2004)

The re-circulating traffic was modeled separately in WATSim as a function of the headway - the ratio of the time period (3600 seconds) for re-circulation and total re-circulatory trips for sides A and B respectively. Thus at about every 11 seconds (side A) and 27 seconds (side B), vehicles were released respectively for re-circulation. The coding followed the bus transit logic, in that a dummy node serving as both exit and entry points were created at the arrival curbs of terminals A and B.

The base network was run and animation generated. Figure 8 through 10 display snapshot animations of the baseline network, terminals A and B after 4,560 seconds of total simulation time.



Figure 8. Snapshot of Animated Base Network of OIA in WATSim

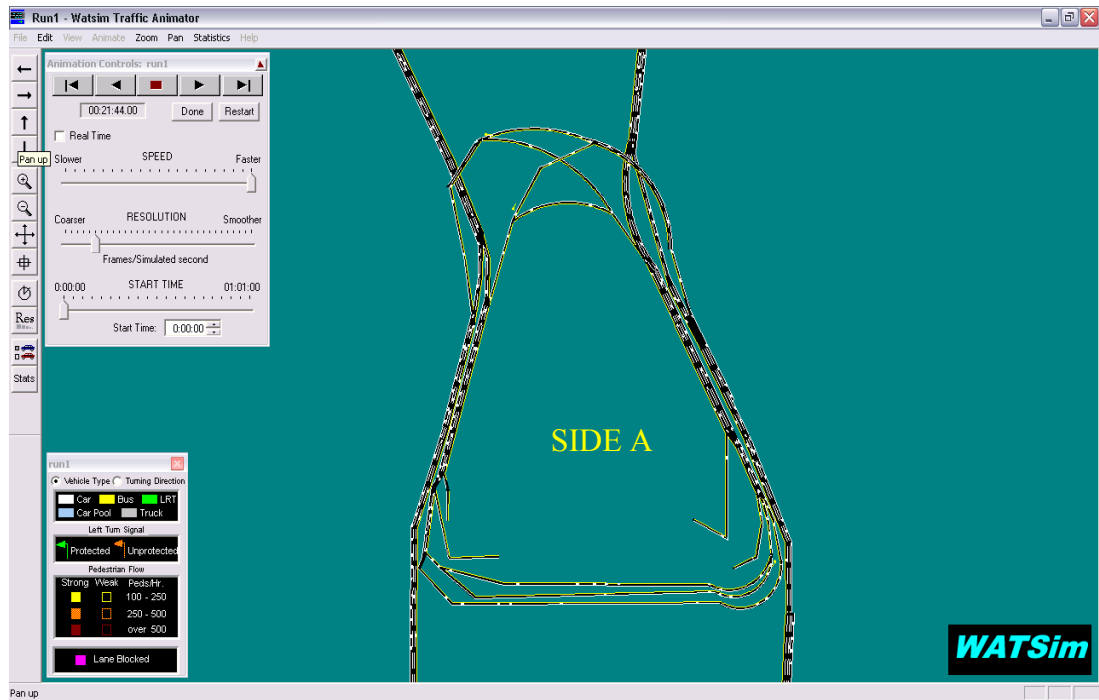


Figure 9. Snapshot of WATSim Simulation of Terminal A with Circulating Traffic

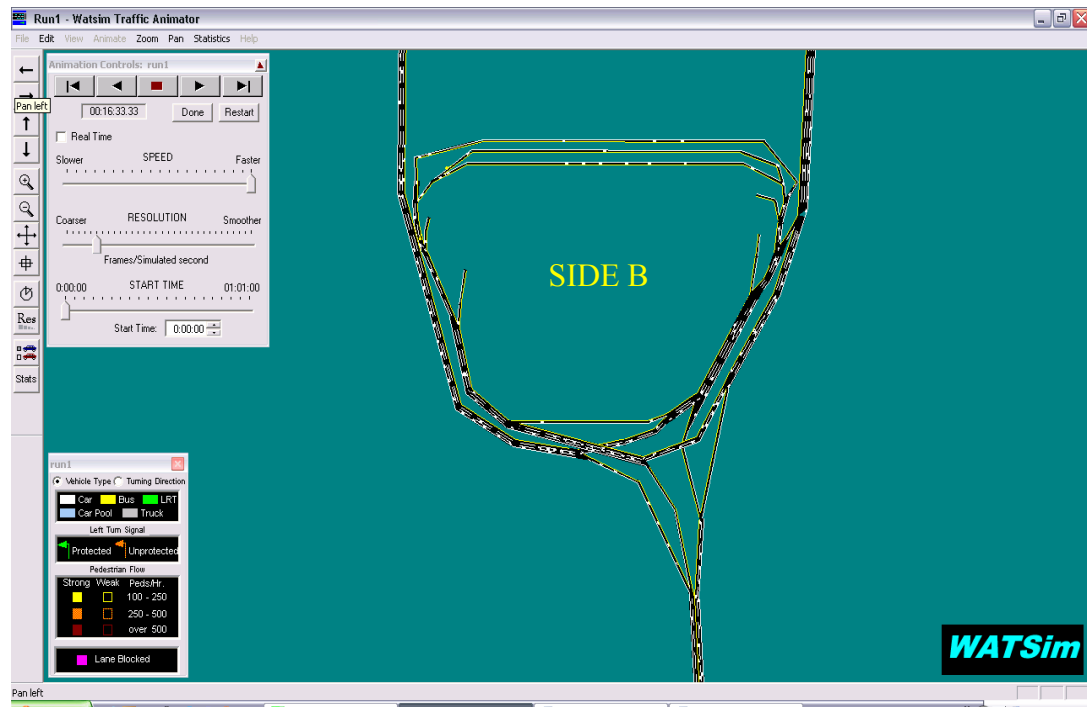


Figure 10. Snapshot of WATSim Simulation of Terminal B with Circulating Traffic

CHAPTER SIX

MODEL CALIBRATION AND VALIDATION

Introduction

Calibration is a process by which the individual components of the simulation model are refined and adjusted so that the simulation model accurately represents field measured and observed traffic conditions. As more and more traffic engineers and researchers begin relying on simulation as an evaluation tool, credibility will become very important and essential concern. Potential issues are whether these models accurately represent the real-world system and/or whether one can trust the decisions based on the simulations. The major parameters of a simulation model that require calibration include the following:

- Traffic flow characteristics
- Traffic control operations

With regards to calibration, traffic simulation models contain numerous variables to define and replicate traffic control operations, traffic flow characteristics, and driver behavior. Simulation models contain default values for each variable, but also allow a range of user-applied values for each variable. In some cases, the variables affect the entire network while others are specific to individual roadway segments or nodes. Changes to these variables during calibration are based on field-measurements.

To achieve adequate reliability of the simulation models, it is important that a rigorous calibration and validation procedures be applied before any further study analysis are conducted. However, one should also take note that achievement of the

overall benchmarks may not always ensure that critical movements within the network are calibrated properly.

Changes to parameters during calibration should be justified and defensible by the users. Most of the calibration efforts were to achieve reasonable correspondence between field data and simulation model output. Recently, more and more transportation researchers and practitioners have realized the importance of model calibration and validation and spent significant time and efforts to demonstrate the validity of their models. However, it was indicated that simulation model calibration and validation often were discussed and informally practiced among researchers, but seldom have been formally proposed as a procedure or guideline (Sacks et al. 2002). Therefore, proposing a general procedure for simulation model calibration and validation is an urgent task.

Dowling et al. (2004) proposed a practical, top-down approach that consisted of three steps. First, capacity at the key bottlenecks in the system was calibrated. Second, traffic flow at non-bottleneck locations was calibrated. Finally, the overall model performance was calibrated against the field performance measures. The authors divided the model into categories and started with the most important parameters, usually global parameters. Then further fine-tuning with link-specific parameters was conducted if necessary. However, the procedure also focuses on a few selected key parameters, which are not easy to identify.

Based on the simulation results, we can compare the observed and simulated total traffic counts at selected measurement locations with the objective function shown in Equation 2 which is to minimize the deviation between the observed and

corresponding simulated traffic counts at selected measurement locations for the whole simulation period. Selected measurement locations include the mainline freeway, and several important arterial links.

Equation 2:

$$\min \sum_{n=0}^N (M_{obs.}(n) - M_{sim.}(n))^2$$

Where $M_{obs.}(n)$ and $M_{sim.}(n)$ are total observed and simulated traffic counts at measurement location (n) for the whole study period, respectively.

The measure of the overall quality of the calibration is the GEH statistic, used by British engineers (1996):

Equation 3:

$$GEH = \sqrt{\frac{(M_{obs.}(n) - M_{sim.}(n))^2}{(M_{obs.}(n) + M_{sim.}(n))^2 / 2}}$$

If the GEH values for more than 85% of the measurement locations are less than 5, the adjusted count is acceptable. An iteration process is required in order to obtain satisfactory results. If the above indices cannot be satisfied, one need to make some modifications to the reference counts

Initial Model Calibration and Validation Analysis

An incremental approach was used for calibration of the simulation time period. Accordingly, some errors were controlled initially. Another issue in calibration was the interaction between errors of various runs. Since each simulation run reduced errors in some links and adversely affected errors in other links, a way of checking the global performance of the run was required. Moreover, checking either the absolute error value (Field volume – Simulated volume) or the percentage error value $((\text{Field volume} - \text{Simulated volume}) / \text{Field volume})$ could be misleading. For example, an error in volume of 300 vph results in a 30% error for a field volume of 1000 vph. On the other hand, 300 vph is 10% if the field volume is 3000 vph. Similarly, 20% of error has a significant meaning for different field volumes (20% of 1000 vph is 200 vph, 20% of 3000 vph is 600 vph).

Sections of SR436, SR528, South Access Road and the main airport were modeled in the base scenario. The model was then run at 3,600 seconds time step under the WATSim default parameters eg. (Vehicle queue discharge headway, Gap, Lane switching lag, Saturation flow rate etc) but the simulated output counts did not match the field counts. Additional time step (15minutes or 900seconds) was introduced into the time period and model run again, this time, Simulation results showed significant improvement compared to the field volumes.

Queue Formation at Terminals

One of the main objectives of this project is to generate reasonable congestion at both terminals of OIA to be as close as to what it is in the real world. However, the simulated base scenario did not yield this congestion at both terminals (A and B) initially. To generate this scenario, the speed of the vehicles at both terminals were reduced and assigned the maximum speed of 10 mph. This time animation did show better agreement on congestion at both terminals when compared to the real world conditions.

Selection of Measures of performance of OIA WATSim Model

The WATSim program provides a wide range of Measures of Effectiveness (MoE) on a link specific basis or aggregated over each sub-network. It produces cumulative output which provides data accumulated since the beginning of simulation.

In order to evaluate the operational conditions, the Measures of Effectiveness (MoEs) must be identified. MoEs are any parameters that assist the analyst in obtaining conclusions about the issue under experimental analysis. Three main MOEs namely, delay, travel time and queue length were selected because of the ease to obtain in the field. The most important is delay which is by far the one the driver feels the most effect from and is measured as percentage time delay. The queue length is directly related to queuing delay, the more the vehicles in the queue, the longer the delay.

Determination of Number of Simulation Runs

As mentioned before, the objective of model calibration is to get the best match possible between model performance estimates and field measurements of performance. However, there is a limit to the amount of time and effort anyone can put into eliminating errors in the model. There comes a point of diminishing returns where large investments in effort yield small improvements in accuracy. The analyst needs to know when to stop.

WATSim is a stochastic simulation model, which rely upon random numbers to release vehicles, select vehicle type, select their destination and their route, and to determine their behavior as they move through the network. Therefore, the average results of several simulation runs using different seed number can reflect the traffic condition of a specific scenario.

In order to determine the number (N) of simulation model runs, we need to know the mean and variance of a number of performance measures from simulation results, which are unknown before simulations. We execute ten simulation runs first time and then calculated the number of runs according to the mean and standard deviation of a performance measure of these ten runs as follows:

Equation 4:

$$N = \left(t_{v, \alpha/2} * \frac{\sigma}{\mu * \varepsilon} \right)^2$$

Where μ and σ are the mean and standard deviation of the performance measure based on the already conducted simulation runs; ε is the allowable error specified as a

fraction of the mean μ ; $t_{v,\alpha/2}$ is the critical value of the t-distribution at the confidence interval of α .

This calculation needs to be done for all performance measures of interest. The highest value from variances is the required number of runs. If the current number of runs is already larger than this value, the simulation of this scenario is ended. Otherwise, one additional run is performed and then the required number of runs needs to be re-calculated (Lianyu, et al. 2003).

Under ideal conditions, the calibration of individual components of a simulation model will improve the model's ability to replicate traffic flow results that match field conditions within an acceptable range of error. The model can be calibrated by comparing simulated vehicle release counts to observed field data. The release count can be varied using seed values. The seed value is a starting value for the random number generator. From this starting value, a set of random numbers is produced. These random numbers are called by the program and used in processes that calculate many different parameters within the simulation. The parameters which use random numbers include car following, lane changing, vehicle behavior, route choice, release of demand and many more processes. Each process will call a random number from the list of random numbers as and when it is required and each calculation will be carried out in order. This means that if the same seed value is used, then the selected run will reproduce the same simulation results every time the network is simulated (provided that the network is not modified).

The network was simulated in WATSim initially using ten seed values 7781, 33, 583, 1021, 2979, 3333, 4843, 6001, 7237 and 5479 chosen randomly for the

calibration of the peak hour traffic counts as shown in Table 5. The software imports data from the central UNITES database and creates a WATSim (.trf) input stream representing the selected network. The Model Interface Processor (MIP) then executes WATSim, which reads that input stream. After WATSim completes its calculations, the MIP software stores the MoE results generated by WATSim, into UNITES database. The output from this WATSim execution is then stored in the UNITES/Project directory. The results may be examined by running the animation or viewing the output file.

The statistical evaluation criterion is computed for the average of the 10 runs and a sample computation for a specific link (Link 13-159) is as follows:

$$n = 10, \mu = 513.50, \sigma = 32.969 \text{ at } \alpha = 5\% \text{ and } \varepsilon = 5\%$$

$$t_{v,\alpha/2} = t_{10-1,0.05/2} = 2.262$$

$$N = \left(t_{v,\alpha/2} * \frac{\sigma}{\mu * \varepsilon} \right)^2$$

$$N = \left(2.262 * \frac{32.969}{513.50 * 0.05} \right)^2 = 8$$

Table 5 shows the results of the first time ten simulation runs and the calculated number of runs needed according to the mean and standard deviation of the simulated counts.

Table 5. Determination of Number of Simulation Runs

LINK	LOCATION	SEED 7781	SEED 33	SEED 583	SEED 1021	SEED 2979	SEED 3333	SEED 4843	SEED 5479	SEED 6001	SEED 7237	MEAN	STD	N(RUNS)
001-49	1	2220	2302	2265	2227	2218	2202	2227	2294	2225	2180	2236.00	39.038	1
49-001	2	1797	1828	1867	1849	1829	1801	1855	1840	1856	1754	1827.60	34.616	1
90-37	3	2230	2259	2297	2232	2281	2247	2262	2292	2252	2255	2260.70	23.036	1
51-003	4	4501	4500	4499	4501	4501	4500	4501	4501	4500	4501	4500.50	0.707	1
002-50	5	4195	4209	4137	4215	4199	4158	4228	4156	4139	4174	4181.00	32.612	1
98-212	6	485	488	532	482	514	507	513	494	516	480	501.10	17.673	3
98-117	7	786	768	770	744	777	791	789	790	749	777	774.10	16.696	1
97-98	8	1273	1255	1305	1228	1294	1300	1302	1287	1268	1256	1276.80	25.275	1
128-143	9	1703	1666	1675	1633	1660	1677	1658	1702	1710	1667	1675.10	23.956	1
143-130	10	1081	1082	1070	1034	1072	1053	1060	1123	1063	1064	1070.20	23.208	1
130-131	11	803	798	803	768	763	787	783	824	794	784	790.70	17.876	1
108-156	12	644	625	592	593	604	612	641	626	577	635	614.90	22.913	3
172-169	13	517	497	488	486	502	488	501	532	519	482	501.20	16.605	2
13-159	14	493	496	511	506	604	510	516	497	511	491	513.50	32.969	8
40-173	15	2145	2123	2165	2130	2151	2138	2140	2195	2123	2132	2144.20	22.024	1

A 95% confidence interval and 5% allowable error were used in the calculation. The minimum number of replications N needed was lower than ten; therefore, no additional simulations were needed.

Analysis of Calibration and Validation Results

The final calibration and validation can not be based on one single run because of the randomness of micro-simulations. Since one computer run is considered as one observation, in this research, 10 replication were conducted for the comparison of calibrated and field results. The simulated counts were compared with the field data counts at 15 selected key link locations critical to the network analysis. In general, simulated traffic counts data corresponded well to the field measurements and accurately capture the congestion patterns of the target road network under the default parameters.

The two statistical evaluation criteria were computed for a specific link (**001 – 49**) as follows:

$$V(n)_{field} = 2237$$

$$V(n)_{simulated} = 2236$$

Equation 5:

$$\begin{aligned} \text{Error } (n) \% &= \frac{(V(n)_{field} - V(n)_{simulated})}{V(n)_{field}} \\ &= \frac{(2237 - 2236)}{2236} * 100 = 0.057 \end{aligned}$$

$$\text{GEH } (n) = \sqrt{\frac{(V(n)_{field} - V(n)_{simulated})^2}{\left(\frac{V(n)_{field} + V(n)_{simulated}}{2}\right)}}$$

$$GEH(n) = \sqrt{\frac{(2237 - 2236)^2}{\left(\frac{2237 + 2236}{2}\right)}} = 0.027$$

Sample of 15 key selected link locations of the OIA-WATSIM network performance calibration results were as provided in Tables 6 and 7. The tables provide the GEH statistic and the error percentages at the 15 key locations (Figure.12). The GEH statistic is a modified chi-squared statistic that incorporates both relative and absolute differences, in comparison of modeled and observed volumes. Generally the GEH static should be used in comparing hourly traffic volumes only. Various GEH values (Oketch and Carrick, 2005), give an indication of a goodness of fit as outlined below:

GEH < 5 Flows can be considered a good fit

5 < GEH < 10 Flows may require further investigation

10 < GEH Flows cannot be considered to be a good fit

Once the model has been calibrated for the existing situation it can then be used to model future scenarios.

Since the re-circulating traffic and the main stream traffic were coded separately, the re-circulation traffic actual count was added manually (Table 6) to that of the main stream and the difference in the re-circulated simulated counts in Tables 6 and 7 accounts for the simulated re-circulating traffic. From Table 7 it can be seen that the difference in the field counted volumes and the model counted volumes lay in the GEH statistic range of 0 to 3. Thus flows can be considered good.

Furthermore, according to (Brockfeld and Wagner, 2003), Relative Error (RE) of 12 to 30 percent can not be suppressed in case of microscopic models. In our case,

RE lay in the range of 0 to 11 percent. Thus the percent differences lay well within the acceptable limits.

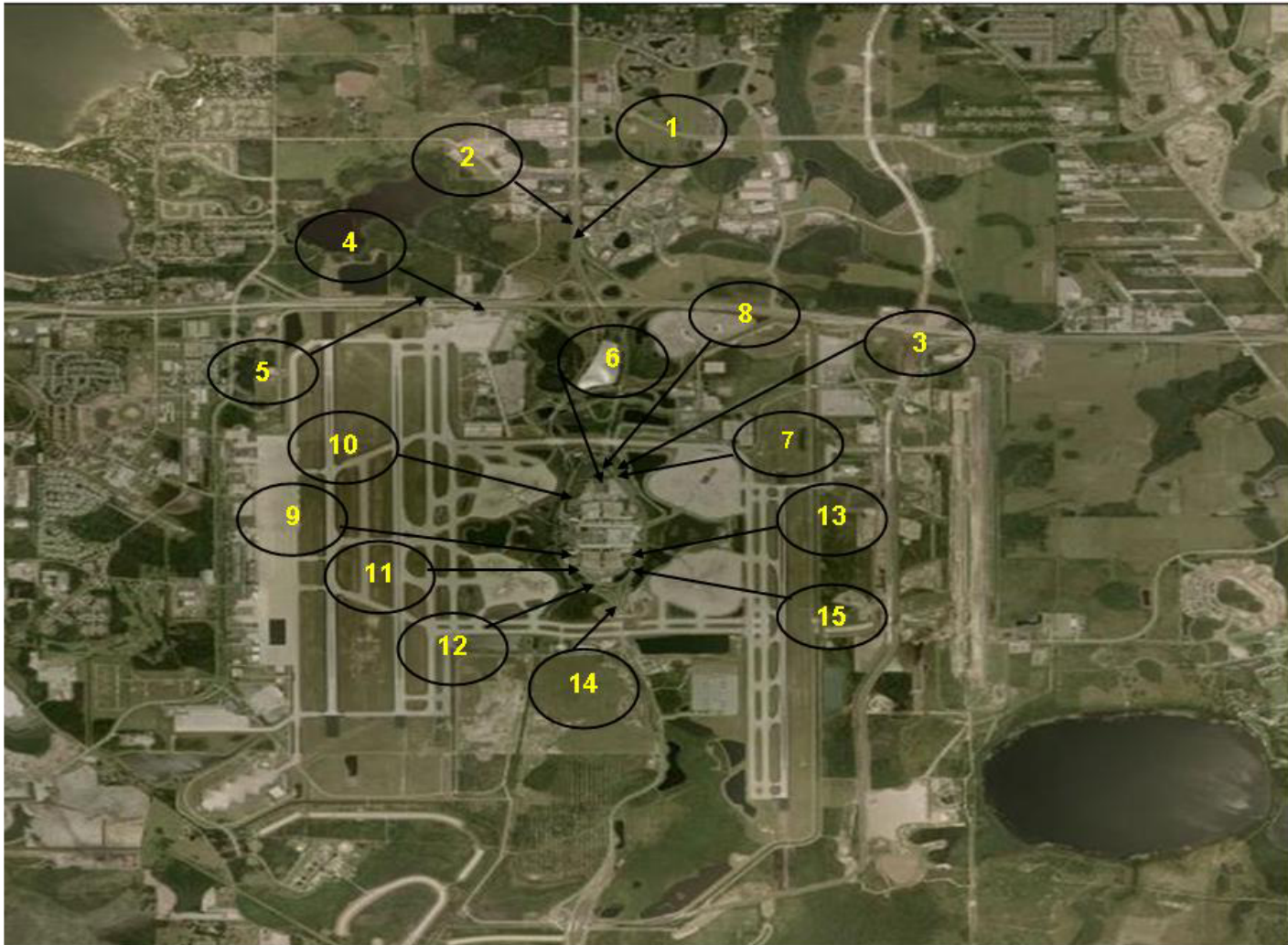


Figure 11. Map showing the fifteen key link locations selected for statistical investigation of model

Table 6. RE and GEH Statistics for 15 selected key link locations without circulation traffic

LINK	Direction	LOCATION	ADT	K	FIELD (veh/hr)	WATSIM (veh/hr)	%ERROR	GEH
001-49	NB	1	27966	0.08	2237	2236	0.057	0.027
49-001	SB	2	22932	0.08	1835	1828	0.379	0.163
90-37	NB	3	29600	0.08	2368	2261	4.531	2.230
51-003	EB	4	55792	0.08	4463	4501	0.832	0.555
002-50	WB	5	52336	0.08	4187	4181	0.140	0.091
SIDE A								
98-212	SB	6	7000	0.08	560	501	10.518	2.557
98-117	CIRC	7	6400	0.08	512	774	51.191	10.336
97-98	CIRC	8	13400	0.08	1072	1277	19.104	5.976
128-143	CIRC	9	18504	0.08	1480	1675	13.158	4.904
143-130	CIRC	10	8856	0.08	708	1070	51.056	12.129
130-131	CIRC	11	6800	0.08	544	775	42.463	8.995
SIDE B								
108-156	CIRC	12	6700	0.08	536	615	14.739	3.293
172-169	CIRC	13	5400	0.08	432	501	16.019	3.204
13-159	SB	14	6910	0.08	553	514	7.109	1.702
40-173	NB	15	27600	0.08	2208	2144	2.889	1.368
MEAN					1580	1657	15.612	3.597

Table 7. RE and GEH Statistics for the 15 selected key link locations with circulation traffic

LINK	Direction	LOCATION	ADT	K	FIELD (veh/hr)	WATSIM (veh/hr)	%ERROR	GEH
001-49	NB	1	27966	0.08	2237	2236	0.057	0.027
49-001	SB	2	22932	0.08	1835	1828	0.379	0.163
90-37	NB	3	29600	0.08	2368	2261	4.531	2.230
51-003	EB	4	55792	0.08	4463	4501	0.832	0.555
002-50	WB	5	52336	0.08	4187	4181	0.140	0.091
SIDE A								
98-212	SB	6	7000	0.08	560	501	10.518	2.557
98-117	CIRC	7	6400	0.08	827	774	6.397	1.870
97-98	CIRC	8	13400	0.08	1387	1277	7.945	3.020
128-143	CIRC	9	18504	0.08	1795	1675	6.680	2.878
143-130	CIRC	10	8856	0.08	1023	1070	4.614	1.459
130-131	CIRC	11	6800	0.08	859	791	7.916	2.367
SIDE B								
108-156	CIRC	12	6700	0.08	667	615	7.796	2.054
172-169	CIRC	13	5400	0.08	563	501	10.977	2.679
13-159	SB	14	6910	0.08	553	514	7.109	1.702
40-173	NB	15	27600	0.08	2208	2144	2.889	1.368
MEAN					1702	1658	5.252	1.565

Model Validation Requirements

According to Law and Kelton (2000), there are two approaches to statistically compare the outputs from the simulation and the field. The two approaches are the visual inspection and the confidence – interval method (t – test). Visual inspection is method is mainly comparing the output in a graphical way, preferably a histogram. The user then eye-balls the histogram bars height to see if there are any significant height differences between the field and the simulated data.

A systematic validation approach of a microscopic simulation model was also described by Zhang and Owen (2004). The procedure includes animation comparison and quantitative/statistical analysis at both macroscopic and microscopic levels. Data at macroscopic level include the averages, other statistics of traffic variables and fundamental relationships of traffic flow parameters. Data at the microscopic level include the speed change pattern, vehicle trajectory plot, and headway distributions. Animation comparison was supplemented to examine the model validity. The procedure emphasized the importance of real-world data-sets to model validation.

The WATSim model was run 10 times and averages of the 15 links counts found and plotted (Figure 13). The visual inspection of the plots showed that there are no major variations between the simulated and the field data.

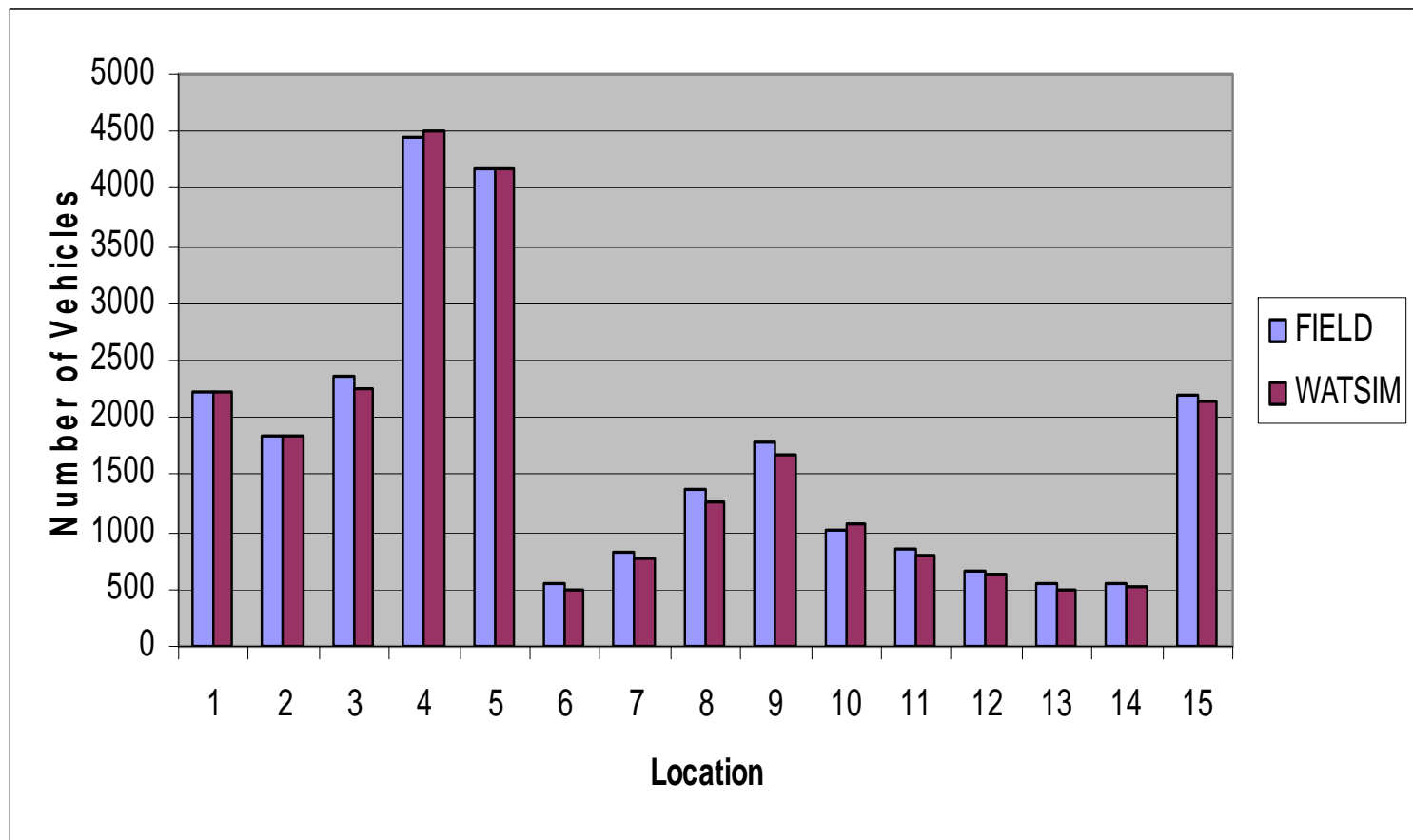


Figure 12. Comparison of traffic volumes from simulation model and field counts

The second approach is the confidence interval, which is a reliable approach for comparing the simulated and the field data. The t-distribution helps in testing whether or not the two sample means come from equal or non-equal populations. The null hypothesis H_o that is tested is:

$$H_o : \mu_f = \mu_s$$

$$H_a : \mu_f \neq \mu_s$$

Where μ_f is the population mean for the field data and μ_s is the population mean for the simulated data. If the null hypothesis is rejected, this infers that the two samples means come from different populations and are different. To compute the two-sample t-test, the mean and the standard deviation were calculated. Using a confidence level of 95%, the method suggested that there is no statistically significance difference between the field data and simulated values for the two data sets. The t-test result is shown in Table 8. Since the test statistic value (0.09575) is smaller than the t critical (2.0484), it is proven that there is no statistically significant difference between the two data sets.

Table 8. T-Test of Field and Simulated Data Counts for the 15 key link locations

Two Sample Means T-Test	Field	Watsim
Mean	1702	1658
Variance	1560001	1607798.64
Observations	15	15
Pearson Correlation	0.9993	
Hypothesized Mean Difference	0	0
df	28	
t - Stat	0.09575	
t - Critical	2.04841	

Variance Ratio F-test

After performing normality test on both samples, it was realized that the two samples follow the normal distribution; hence the variance test is carried out to ascertain if the two data has equal sample variances or not so we could determine the appropriate method of approach to the t-test.

$$H_o : S_f^2 = S_s^2$$

$$H_a : S_f^2 \neq S_s^2$$

$$F_{calc.} = S_{\max}^2 / S_{\min}^2$$

$$\bar{x}_f = 1692.67$$

$$\bar{x}_s = 1681.07$$

$$S_f = 1236.48$$

$$S_s = 1244.13$$

$$n_f = n_s = 15$$

$$F_{calc.} = 1607798.64 / 1560001 = 1.0306$$

$$F_{calc.} (1.0306) < F_{table} (2.97859) ; df = (14, 14)$$

Hence, we fail to reject H_o . Variances are equal for the two data sets). We proceed to perform the t-test using the equal sample variance as shown below.

$$H_o : \mu_f = \mu_s$$

$$H_a : \mu_f \neq \mu_s$$

$$S_p^2 = \frac{(n_f - 1)S_f^2 + (n_s - 1)S_s^2}{(n_f + n_s - 2)}$$

$$S_p = 1583912.5$$

$$\text{Test Statistic } t = \frac{\bar{x}_f - \bar{x}_s}{\sqrt{\frac{S_p^2}{n_f} + \frac{S_p^2}{n_s}}}$$

$$\text{Test Statistic } t_{calc.} = 0.09575$$

$$\text{at } \alpha=0.05/2, \text{ df}=15+15-2=28$$

$$t_{table} = 2.04841$$

$$t_{calc} < t_{table}$$

Therefore, we fail to reject H_0 , the two sample means comes from the same population.

Description of the Hypothetical Emergency Events and Simulation

Event 1: Exclusive Incident Modeling on South Access Road without diversion

An incident is any random event that causes a temporary reduction in roadway capacity. Incidents may or may not be predictable events in terms of occurrence time, extent, and location. The most common type of unpredictable incident is a traffic crash. Incident management in response to a traffic crash may include on-site traffic control, motorist information dissemination and activation of emergency personnel to the incident location. The unique geographic, environmental, and institutional characteristics of the region, as well as available resources and local incident management goals and priorities often play a role in the selection of a plan of action in response to a traffic incident related emergency.

The scenario assumed the occurrence of a traffic incident at the South Access road northbound direction, and studied its impact on the network operations. More specifically, the incident was modeled on (link 20-19) northbound as shown in Figure 14.

Fifteen minutes incident was then modeled exclusively on (link 20-19) and the average travel times for northbound vehicles during the incident duration were observed from the intersection of South Access and Heintzelman Blvd at node 207 (Figure 14) to Sides A & B. The average travel times for both base case and the scenarios were then compared as shown in Table 9. The average travel time to Side A in scenario 1 was 15 minutes more than the base case where as that of Side B was 14 minutes more. The overall network performance in terms of delay for the baseline was 199 sec/veh and that of the scenario 1 was found to be 231.09 sec/veh.

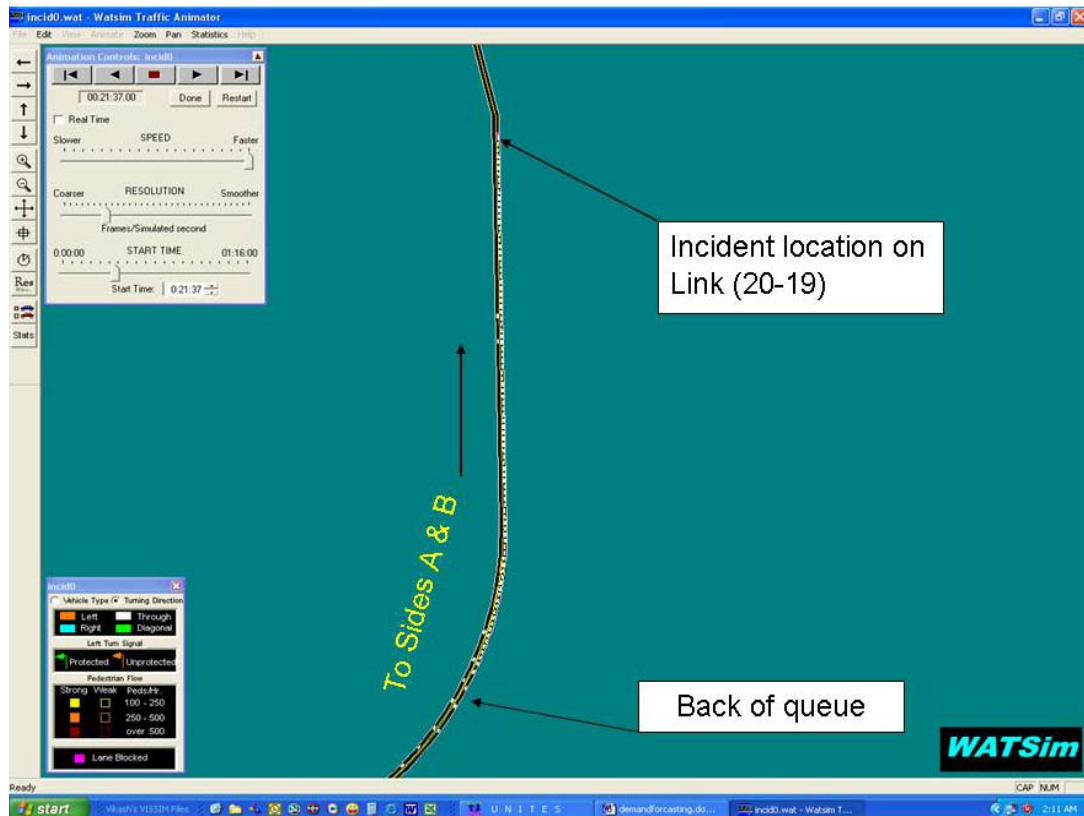


Figure 13. Incident location on South Access Road Northbound direction without diversion

Table 9. Event 1: Travel time measured from intersection of South Access and Heintzelman roads to sides A and B

CONDITION	MOE	
	TRAVEL TIME SIDE-A (min)	TRAVEL TIME SIDE-B (min)
Base	14.00	9.00
Event 1	29.00	23.00

Event 2: Incident Modeling on South Access Road with diversion

In modeling this event, two scenarios were assumed and evaluated, in the first scenario; 15 minutes incident was modeled at the same link and spot of the South Access road as in event 1. It is assumed that no traffic was diverted to alternate route (Heintzelman road), due to the lack of advanced information dissemination technologies. Under the second scenario, it was assumed that information about the incident was disseminated upstream of the incident 2 minutes after the incident occurred. As a result, 26 percent of traffic was diverted upstream through Heintzelman Blvd at node 207 to sides A and B in response to the dissemination of incident information. After the incident was removed, traffic operations returned to their original pattern. Figure 15 below shows the location of event in WATSim.

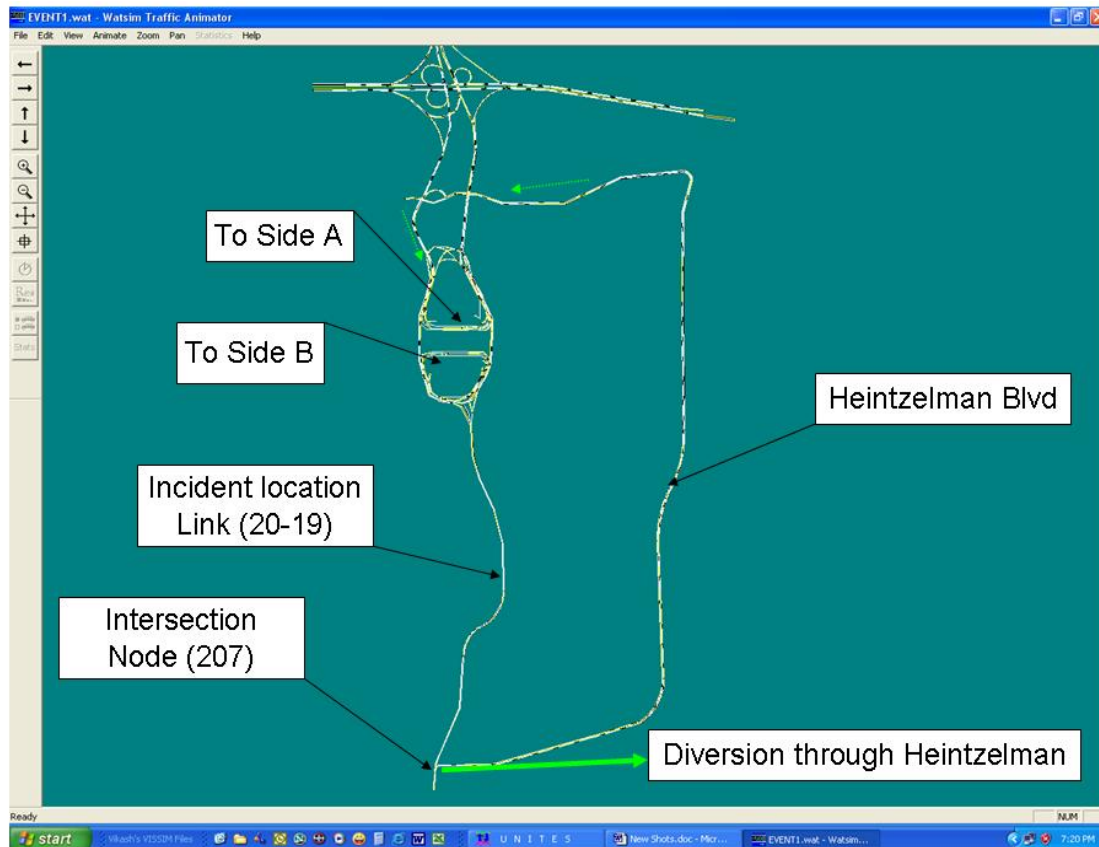


Figure 14. Incident with diversion at South Access Road and Heintzelman intersection

Similarly, ten runs were performed for each study scenario and the average travel times to both sides A and B were recorded and compared to that of the baseline as shown in Tables 10 and 11. For Event 2 first case, the average time traveled by vehicles to terminal A from the intersection of South Access and Heintzelman roads without diversion for the base condition was 14 minutes and terminal B (9minutes). Comparatively, the average time taken to travel to terminal A in Event 2 first case was more than twice that of the baseline and almost two and half times in the case of Side B. However, in the event of re-routing (Event 2 case two) to Sides A and B, there was a significant reduction in the average travel times (17 minutes to Side A)

and (19 minutes to Side B) compared to the base condition. Also similarly by comparing just cases (1 & 2), there was a significant reduction in the average travel times, 12 minutes less to Side A and 4 minutes less to Side B. Clearly, the second scenario performed better and it was as a result of the advanced information technology assumed to be implemented. However, not all drivers would like to divert in the real world after receiving the advance information, the WATsim version used does not have the ITS capability to achieve this condition, thus on the average 200 vehicles were completely diverted during the incident. The overall network performance in terms of delay for this event was also found to reduce significantly (166.92 sec/veh) compared to the base (198.9 sec/veh) but with increased average travel time.

Table 10. Event 2: Northbound South Access without diversion

Condition	MOE	
	Travel Time A-SIDE (min)	Travel Time B-SIDE (min)
Base	14.00	9.00
Event 2	29.00	23.00

Table 11. Event 2 Diversion through Heintzelman Blvd

Condition	MOE	
	Travel Time A-SIDE (min)	Travel Time B-SIDE (min)
Base	14.00	9.00
Event 2	17.00	19.00

The scenario explored in Event 2 looked at the effect of diversion on traffic performance under incident conditions. Diversion, in turn, relates to the availability of technologies that:

- a. Collect traffic information and use them for incident detection and verification, and
- b. Deliver incident-related information to the travelers.

Examples of such technologies include Closed Circuit TV Cameras (CCTV), HAR, VMS, and web communications, etc. Thus, while testing the impact of diversion in Case 2, one can also indirectly assess the criticality of the presence of ITS in support of incident management.

Event 3: Security Check Point Modeling

Being one of the sensitive places for possible terrorist attacks, security checks are randomly conducted periodically around the OIA region. However, there is no explicit security checkpoint coding capability in WATSim, therefore the security checkpoint (Figure 16) was coded into WATSim as a result of creating a bypass link along link (220 – 221) Airport Blvd southbound close to Side A. A dummy signal control with several cycle lengths ranging from 100 seconds and up to exactly 180 seconds (3 min) were simulated on this link in order to get a close match to what pertains in the real world. Only a cycle length of 157 seconds was able to produce reasonable visualization to depict the local conditions. Thus, about five vehicles are checked simultaneously every 157 seconds assuming there are five security personnel stationed. Prior to this, the speeds of vehicles traveling southbound close to the checkpoint vicinity were reduced from 45mph steadily to 10mph in order to capture the effect of the local condition.

The average travel times to Sides A and B were then observed by tracking vehicles from a reasonable spot close to back of queue (Figure 16).

The summaries of results are as shown in Table 12. The average travel times to Sides A and B for the base and scenario 3 conditions seem fairly significant. However, the overall network performance in delay was 210 sec/veh compared to 198.9 sec/veh of base scenario.

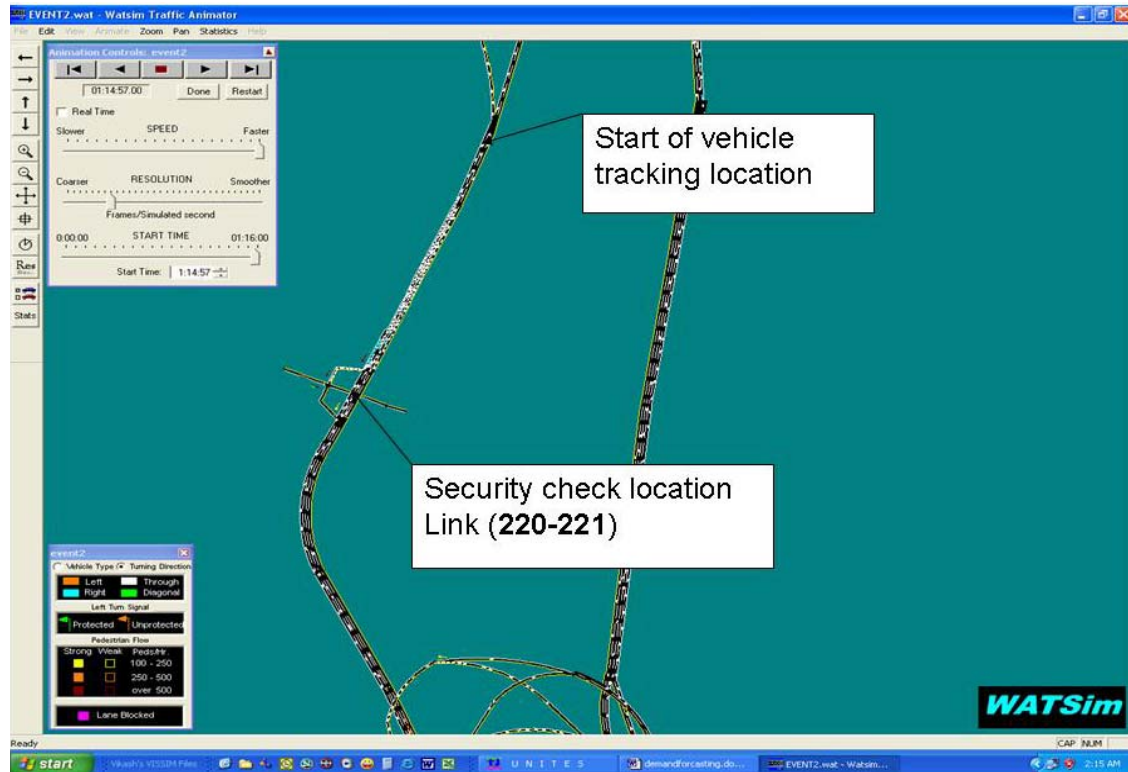


Figure 15. Location of Security Checkpoint

Table 12. Event 3: Travel time to sides A and B

CONDITION	MOE	
	TRAVEL TIME A-SIDE (min)	TRAVEL TIME B-SIDE (min)
Base	5.00	8.00
Event 3	9.00	13.00

Furthermore, the MOEs, queue length and the number of vehicles in queue were selected. This is because of their ease to obtain in the field. Generally the maximum queue is obtained in the field by multiplying the number of vehicles that completely stop in the queue by 20 feet (15feet length of the car plus 5 feet distance between the stopped cars). In Table 13, several vehicle queue lengths were measured from animation and averaged to be 650 feet consisting of 32 vehicles in queue. However, in Table 14, vehicle queue length of 890 feet consisting 45 vehicles was obtained as the worst situation.

Table 13. Event 3: Security check point (SB Semoran Blvd)

CONDITION	MOE	
	Queue Length	Number Vehicle in Queue
Base	0ft.	0
Event 3	650ft.	32

Table 14. Event 3: Security checkpoint (SB Semoran Blvd) worst case

CONDITION	MOE	
	Queue Length	Number Vehicle in Queue
Base	0 ft.	0
Event 3	890ft.	45

Event 4: Traffic Demand Forecasting - Loading the Network beyond Capacity

The city of Orlando is growing at a very fast pace. The aim of this scenario was to determine when and where the OIA network breaks down. In order to achieve this, ten different demand sets (Table 15) were created by increasing the base demand simultaneously percentage wise and entered at the four (North – Node 78, West – Node 51, East – Node 48 and South – Node 208) major entry points of the network and modeled simultaneously.

Table 15. Demand set created for the four major entry points

Demand Set #	Demand (veh/hr)			
	North	West	East	South
0 (Base)	1,755	4,463	3,800	784
1 (5%)	1,843	4,686	3,990	823
2 (10%)	1,931	4,909	4,180	862
3 (15%)	2,018	5,132	4,370	902
4 (40%)	2,282	5,802	4,940	1,019
5 (40%)	2,457	6,248	5,320	1,092
6 (50%)	2,633	6,695	5,700	1,176
7 (60%)	2,808	7,141	6,080	1,254
8 (70%)	2,904	7,587	6,460	1,333
9 (90%)	3,159	8,033	6,840	1,411
10 (90%)	3,335	8,480	7,220	1,490

However, due to non-availability of appropriate data, the demand increments were calculated uniformly and entered at all the four major entry points of the network at the same time but however this is hardly the case in the real world since it is expected that growth may be non-uniform at this points.

The base condition was then compared visually and statistically (MOE) to the ten demand set conditions as shown in Figures 17 through 24 and Table 16 respectively.

The numbered links (1, 2, 3 and 4) in these Figures are locations liable to extreme traffic congestion determined by the aid of the computer animation

Although the aim of this event was not achieved instantly, there was some significant effect at certain locations in the network as the network is loaded steadily. By the aid of the computer animation, 70, 80 and 90% increase in demand seemed to have shown consistent gradual impact on the network at the merge of Airport Blvd. Northbound near the on-ramp of SR 528 EB, upstream to a point east side of A, (Figures 19 through 24).

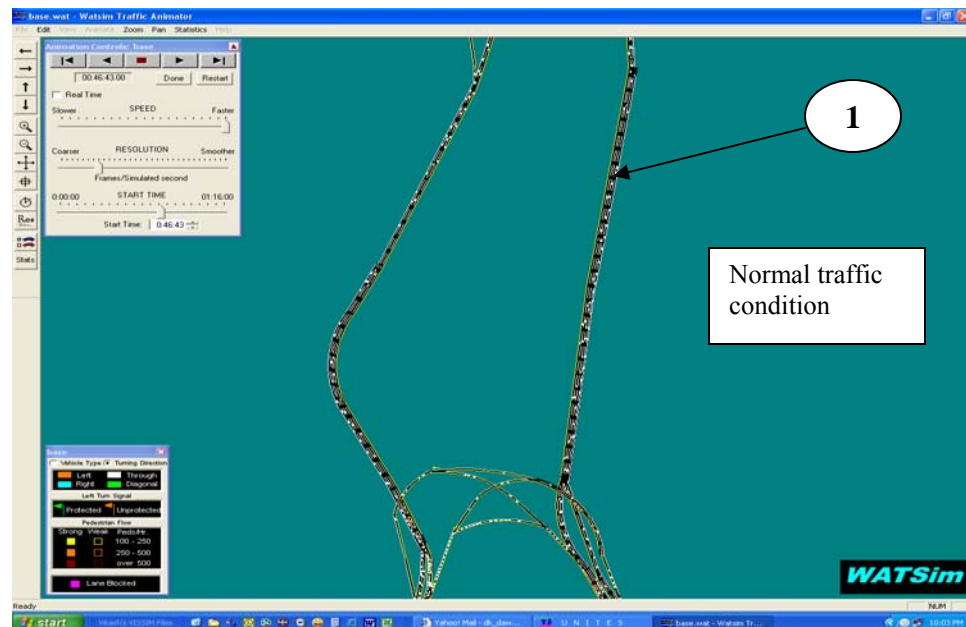


Figure 16. Snapshot of Base Conditions

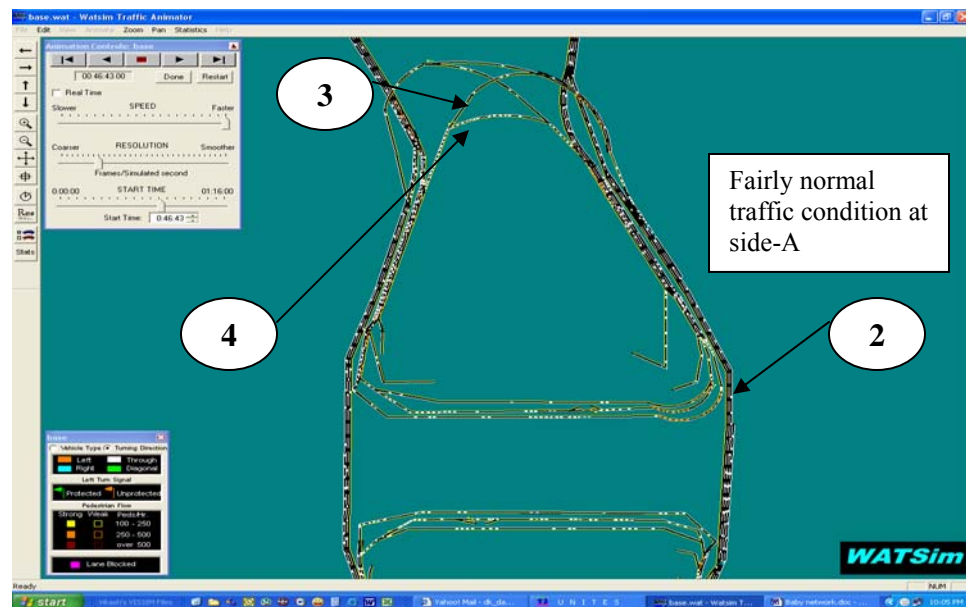


Figure 17. Snapshot of Base condition at Terminal A

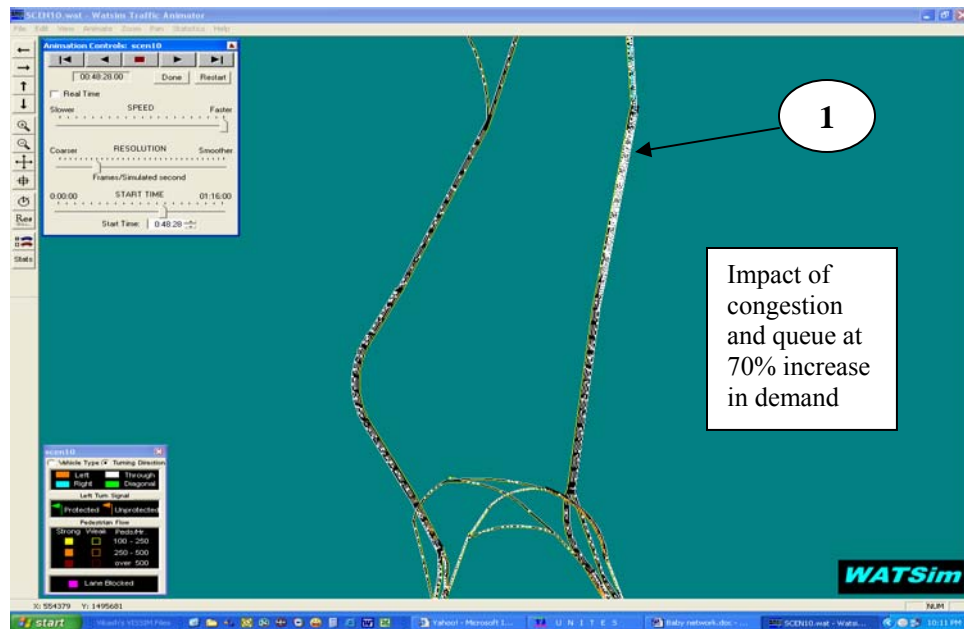


Figure 18. Effect of 70% increase in demand

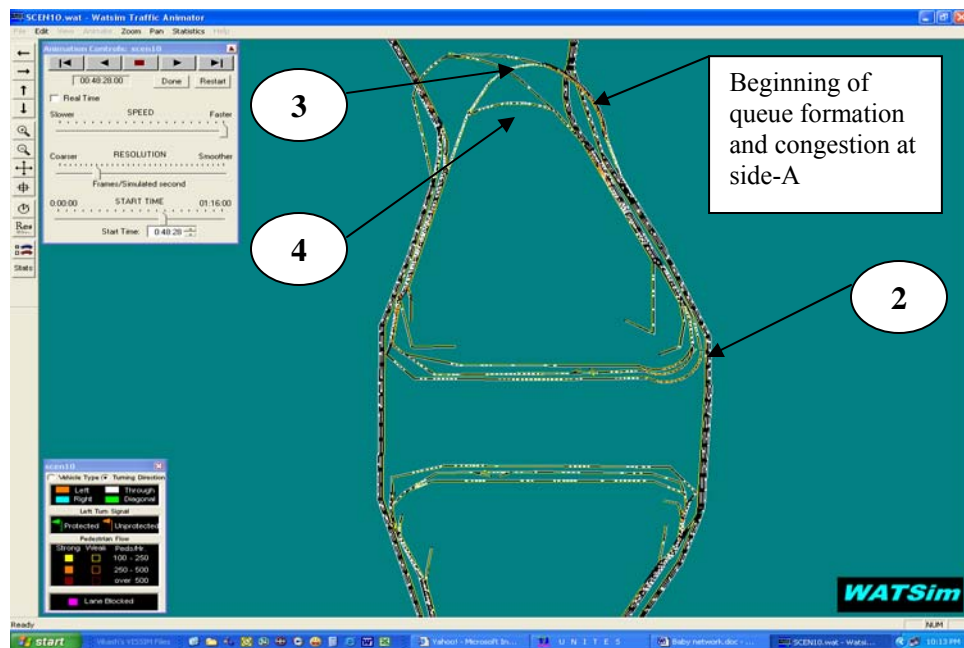


Figure 19. Effect of 70% increase in demand at Side-A

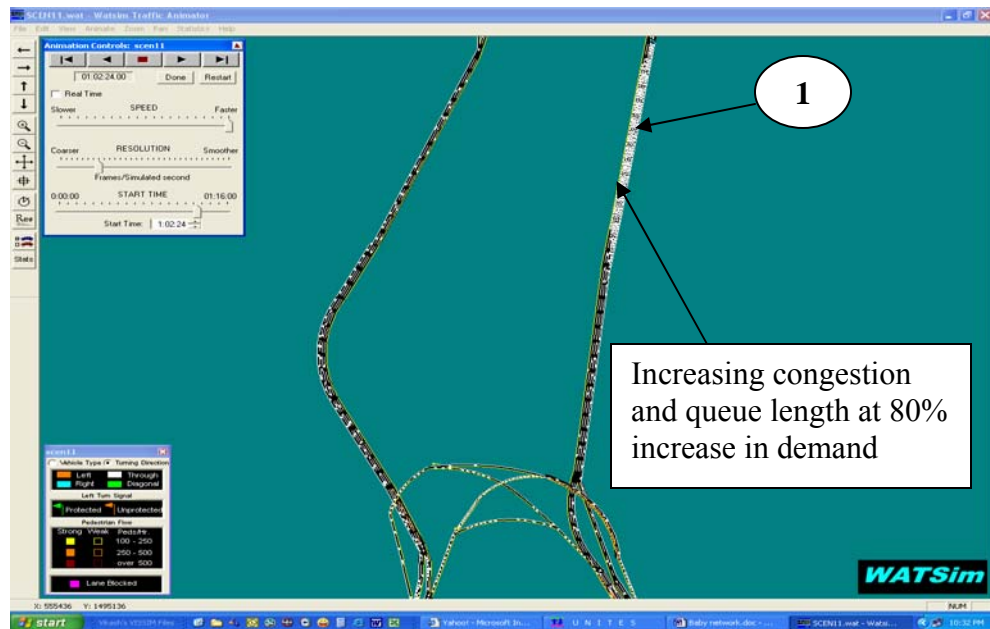


Figure 20. Effect of 80% increase in demand

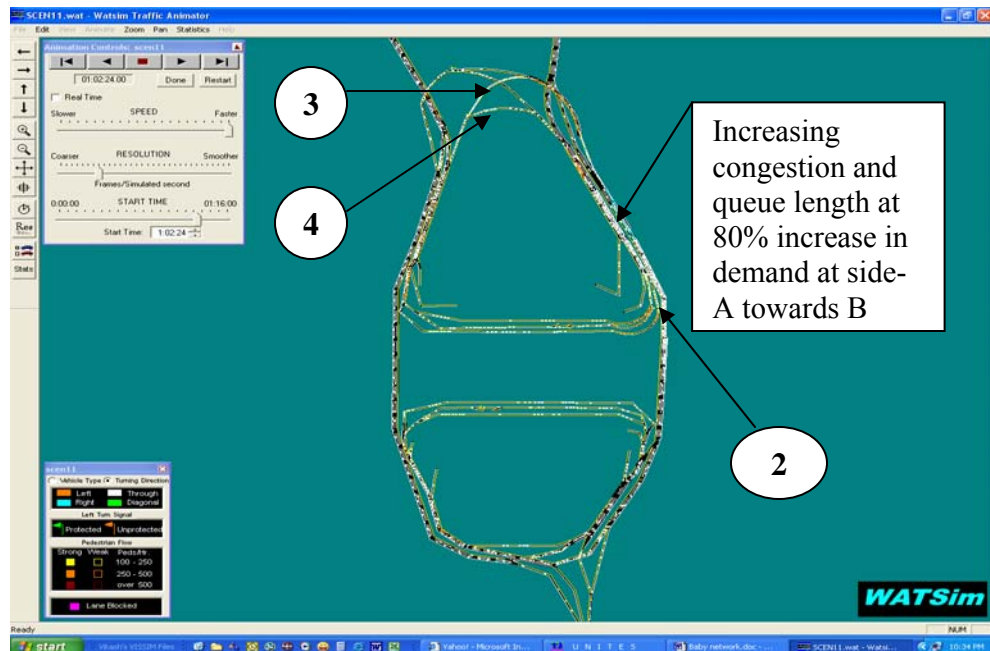


Figure 21. Effect of 80% increase in demand at Side-A

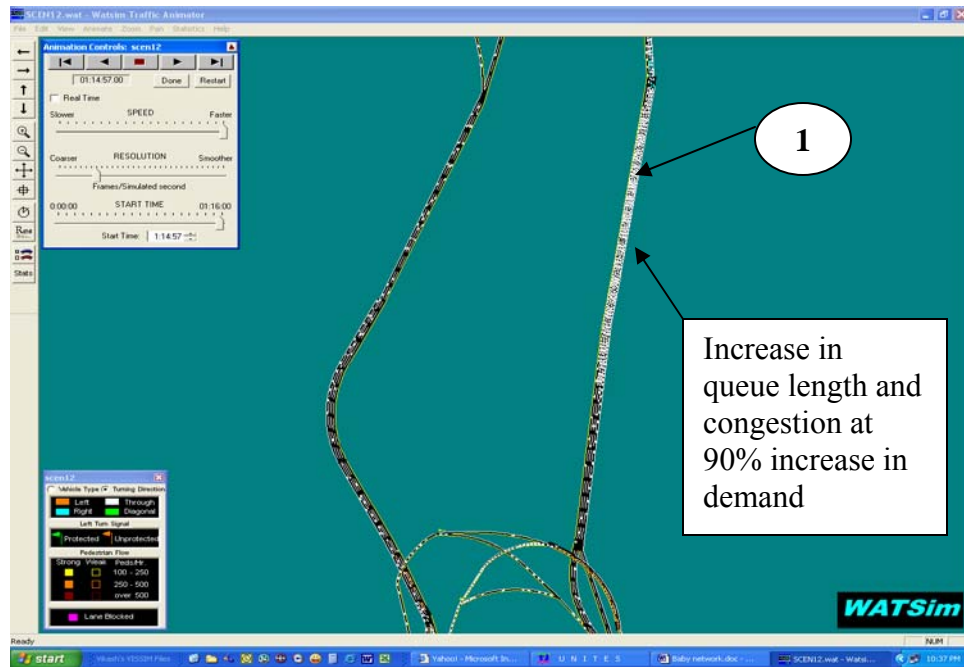


Figure 22. Effect of 90% increase in demand

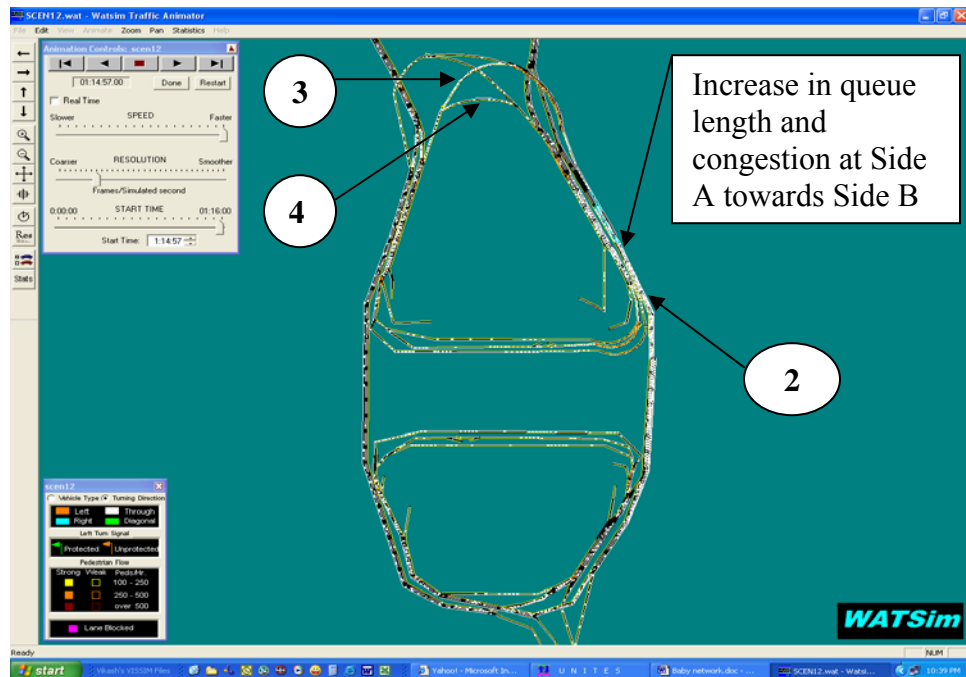


Figure 23. Effect of 90% increase in demand at Sides A & B

Delay (sec/veh.) was selected as MOE for Event 3. Network-wide, it was observed that as the demand was increased steadily, the MOE's also kept increasing steadily in each instance (Table 16). Based on the delay values, it appeared that the network started breaking down at the 30% increase in demand with 90% increase having the most severe effect on the network with a total network-wide delay close to 620 seconds per vehicle.

Table 16. Overall network-wide Performance for all scenarios in Event 3

MOE	BASE	5%	10%	15%	30%	40%	50%	60%	70%	80%	90%
Delay (sec/veh)	198.85	214.25	233.82	257.64	353.18	423.99	516.93	548.82	578.82	597.33	619.38

The Level of Service (LOS) was also used as a qualitative measure of the traffic stream operation conditions as the network was loaded. Since the network was coded at peak values, it is expected that the network links operates at near capacity, therefore before increasing the network demand; most of its links were already operating between LOS D and E for the base condition.

The LOS was determined from the WATSim output Density (pc/mi/ln) by comparing it to the density ranges in the HCM (page 23-3) shown on next page:

LOS Density Range (pc/mi/ln)

A	0 - 11
B	> 11 – 18
C	> 18 – 26
D	> 26 – 35
E	> 35 – 45
F	> 45

The links selected and investigated are network locations (numbered 1, 2, 3, and 4) that showed the potential of breaking down. The LOS at the base condition of the selected link locations were then compared to the LOS of same link locations in the case of increasing demand conditions, (Table 17). Table 17 displays the LOS of the selected link locations deemed problematic. It is observed that the network appeared to be showing early signs of breaking down at 15 % increase in demand and experienced consistent effect from 30 to 90% increase based on the LOS.

Table 17. LOS Summary for Selected Links

LOCATION	LOS										
	Base	5%	10%	15%	30%	40%	50%	60%	70%	80%	90%
1	E	E	E	E	E	E	E	E	F	F	F
2	E	E	E	F	F	F	F	F	F	F	F
3	E	E	E	F	F	F	F	F	F	F	F
4	D	D	D	D	D	D	D	D	D	D	D

Summary of Overall Network-wide Performance for All Scenarios

As can be seen in both Table 17 and Figure 25, the best network wide performance in terms of Delay (sec/veh) but with an increased travel time was achieved in Event 1 scenario 3 with the aid of advanced dissemination technology. The delay for the 90% increase in demand is almost three and a half times that of the baseline, thus very significant.

Table 18. Network-wide comparison of Delay for all Scenarios

Condition	MOE
	Overall network delay (sec/veh)
Base	198.90
15 min incident without diversion through Heintzelman Blvd	231.09
15 min incident with diversion through Heintzelman Blvd	166.92
Security check	210.00
90% increase in demand	619.38

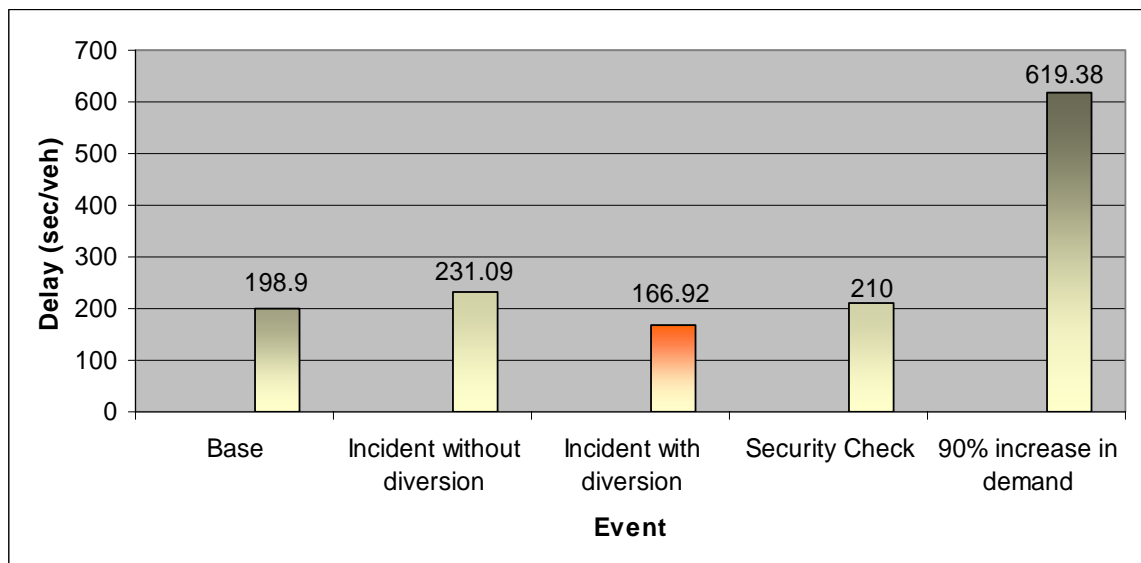


Figure 24. Overall network-wide performance for all scenarios

Some Drawbacks encountered with Watism in modeling the OIA network

In using WATSim (academic version), the following drawbacks were encountered:

1. Can only model incident duration in the range of 0 to 999 seconds (17 minutes)
2. No lane restriction coding like other softwares like, e.g., Paramics, Vissim
3. Cannot block more than 1 lane at the same time

CHAPTER SEVEN

CONCLUSIONS AND FUTURE SCOPE

Summary and Conclusions

Transportation officials and professionals alike recognize the vitality of the transportation system in case of emergencies. Terrorist acts or natural disasters may directly target the transportation system infrastructure and disrupt traffic operations. In other instances, transportation system components may be used as the method of delivery of an attack. Even when emergencies do not directly occur on the transportation system they still have a transportation component since the transportation network is the primary method through which response and recovery are carried out. Therefore, it becomes imperative to safeguard the transportation system and take all necessary steps to ensure acceptable system performance under emergency conditions.

Emergency preparedness is vital to ensure the safety, security, and efficiency of the transportation system in the event of natural or manmade disasters. It has been recognized that emergency preparedness can greatly benefit from the development of a range of realistic emergency scenarios and testing of plans to respond to each scenario. More specifically, after emergency scenarios are developed, the consequences of emergencies on the operation of the transportation infrastructure should be assessed.

Given the magnitude of the problem and availability of resources, possible response actions can be identified and evaluated and necessary adjustments be made

to the original plans, when feasible, to minimize the disruption to transportation operations resulting from the emergency. Assessment of emergency scenarios and response actions can be performed through tabletop exercises, mock exercises (drills) or simulation modeling. The latter approach is particularly important for assessing the impact of emergencies and response actions on the transportation network operations without the need to disrupt traffic operations while testing.

This thesis shows how microscopic traffic simulation can be used to assist decision making for emergency preparedness through a series of case studies implemented on a limited OIA's transportation network. Details are offered on simulation model selection, data collection, model calibration and validation, emergency scenario development and testing. The objective of each event study was twofold: First, to offer examples of common emergencies (such as traffic incidents, crash etc) and evaluate their impact on network performance. Second, to introduce strategies for traffic management (e.g. traffic diversion, access restriction, etc) and assess their potential benefit on traffic operations). Overall, the work reported in this research study demonstrates the feasibility of the simulation approach in emergency preparedness and highlights some of the challenges in the development of WATSim microscopic simulation model.

This research project presents the results of several hypothetical transportation emergencies in the OIA region. The purpose was to demonstrate the usefulness of micro-simulation modeling in developing appropriate emergency preparedness plans. Useful measures of effectiveness (MOEs) were selected to support the assessment process.

The study contributions can be briefly summarized as follows:

- 1) The study identified and addressed issues critical to emergency preparedness through literature synthesis and application of the simulation model.
- 2) WATSim (academic version) transportation model was developed comprised of some major highways, and some major arterials in the OIA area. The coded network consists of 3 signalized intersections, 180 nodes and 230 links. The simulation model development was a major undertaking that involved extensive data collection, processing, data coding, and validation efforts. The developed model will be available in future testing and evaluation studies, with some minimum requirements for data collection and coding
- 3) The results of this research have demonstrated the potential benefits of using the traffic simulation model WATSim for emergency preparedness modeling. The study is expected to provide some insight to future research efforts focusing on simulation modeling for assessment and testing of traffic management options under emergencies.
- 4) The WATSim animation output files can be a useful tool for demonstrating the impact of a simulated strategy on the transportation network operations. This capability can be particularly useful for helping participating stakeholders visualize the impacts associated with adoption of a particular plan.
- 5) The various scenarios that were tested in our case can be useful for GOAA planning and emergency preparation strategies.

In all 4 main Events were modeled and analyzed in the WATSim (Academic version).

In Event 1, it assumed exclusive occurrence of 15 minute traffic incident on a section of South Access Road Northbound direction, and studied its impact on the network operations. The averaged travel time to Side A was more than doubled (29 minutes, more than a 100% increase) compared to base case and similarly that of Side B two and a half times more (23 minutes, more than a 100% increase). The overall network performance in terms of delay for the baseline was 199 sec/veh and that of the scenario was found to be 231.09 sec/veh.

In modeling Event 2, two scenarios were assumed and evaluated, in the first scenario, again 15 minutes traffic incident was modeled at the same link and spot as in event 1. It was assumed that no traffic was diverted to alternate route (Heintzelman road), due to the lack of advanced information dissemination technologies.

Under the second scenario, it was assumed that information about the traffic incident was disseminated upstream of the incident 2 minutes after the incident occurred. As a result, about 26% of traffic was diverted upstream through Heintzelman road to Sides A and B in response to the dissemination of incident information.

The scenarios explored in Event 2 generally looked at the effect of diversion on traffic performance under incident conditions. In analyzing Event 2 first scenario, the average time traveled by vehicles to terminal A from the intersection of South Access and Heintzelman roads without diversion was 29 minutes and for the base, 14 minutes. Thus comparatively, the average time taken to travel to terminal A in event 2 first scenario was 15 minutes more than that of the baseline and 14 minutes more for

that of Side B. However, in the event of re-routing (Event 2 second scenario), there was a general significant reduction in average travel time (17 minutes) to Side A and (19 minutes) to Side B with respect to baseline conditions. Similarly by exclusively comparing both scenarios in Event 2, there was a significant savings in the average travel times per vehicle to Sides A and B. There was clearly, 4 minutes and 12 minutes travel time savings to Sides B and A respectively. Obviously, the second scenario performed better than the first and this was as a result of the advanced information technology assumed to be implemented. Thus results of the second event study showed significant improvement of network performance with the traffic diversion strategy. The findings may lead to the conclusion that investment in ITS technologies that support dissemination of traffic information (such as Changeable Message Signs, Highway Advisory Radio, etc) would provide a great advantage in traffic management under emergency situations. It also shows how an evacuation could be carried out with different strategies (e.g., diversion strategies).

The overall network performance in terms of delay for this event was also found to be (166.92 sec/veh) and also indicates a significant reduction in delay compared to the baseline (198.9 sec/veh).

Event 3 was the modeling of Security Check point and studying the impact of travel times to Sides A and B. It was observed that the average travel times to Sides A and B were 3 and 5 minutes more respectively compared to baseline 5 minutes to Side A and 8 minutes to Side B. The differences in the travel times are fairly significant. However, the overall network-wide performance in terms of delay was 210 sec/veh compared to 198.9 sec/veh of base scenario.

Additionally, queue length and the number of vehicles in queue were selected as measures of performance. Several vehicle queue lengths were measured from animation and averaged to be 650 feet consisting of 32 vehicles. For the worst case, vehicle queue length of 890 feet consisting 45 vehicles was obtained. There were no queues observed in the baseline condition

Since the City of Orlando is growing at a very fast pace, the aim of Event 4 was to determine when and where the network breaks down when loaded. Even though the aim was not achieved instantly, there was some significant effect at certain locations in the network as the network is loaded steadily and simultaneously. Of the 10 sets of demand created in percentage wise, only 70, 80 and 90% increase in demand showed consistent gradual impact on the network specifically at the merge of airport blvd north bound and on-ramp SR 528, downstream to a point east side of B.

In addition to the animation inspection, Delay in (sec/veh.) was chosen as MOE for Event 3. Network-widely, it was observed that as the demand is increased steadily, the MOE also kept increasing steadily. Among these sets of demand, 90% increase in demand had the most effect on the network with a total network-wide delay close to 620 seconds per vehicle which is 3 and a half times compared to baseline 198 seconds per vehicle.

While the network coded in WATSim was a significant achievement, it is limited in its ability to simulate emergencies in real time and does not model driver behavior at the network level. As a result the tested scenarios have only limited impacts and do not capture the real dynamics of emergency planning.

Suggested Future Works

A future extension of this work should involve the integration of the WATSim microscopic transportation model and a dynamic traffic assignment model in an attempt to develop a comprehensive model for emergency planning. The addition of the traffic assignment model will allow modeling of travel behavior at a network level and will produce route choices of users under emergency conditions, providing a more comprehensive representation of the distribution of traffic in a dynamic way. The WATSim transportation network developed in this study can be used as the test bed for the development and testing of the integrated model. This will be a very valuable tool for incident and emergency management. Moreover, the integrated model will have the potential to support a variety of GOAA and FDOT goals related to traffic management and alternatives assessment at the regional level, including access management, traffic impact analyses, and asset managements studies.

Some future work that can be derived from this research and analysis study includes:

- 1) Using the network to test additional emergency management strategies such as contra flow operations in response to an emergency evacuation or traffic signal preemption for emergency vehicles.
- 2) Using the model to determine the shortest paths for routing emergency response units to and from the affected area. Knowledge of the exact location of emergency response units would enable estimation of response time for areas likely to be affected, and would facilitate an effective deployment of emergency responders.

- 3) Conducting simulations for large-scale evacuation scenarios such as a terrorist attack or a release of hazardous materials in Downtown Orlando
- 4) Investigating the potential of using high performance computing for three-dimensional (3-D) traffic flow visualization. This will involve development and testing of a 3-D animation software as an extension of WATSim. The outputs from the WATSim model and geographical and topographical data can be used for demonstration purposes. Such a tool will allow transportation and emergency response agencies to clearly visualize traffic conditions and better grasp the impact of proposed emergency management strategies on transportation network operations.

Additional recommendations for future research include the following:

- 1) Previously prepared plans can be tested using simulation to assess their validity.
- 2) Conducting a study to determine current needs for deployment of ITS technologies in support of emergency management objectives in the OIA region and options for integrating/sharing information (data, voice, images) from traffic management centers with emergency management centers and/or other first responder centers.
- 3) Determine routes in the Florida region that are critical under regional emergencies and develop an inventory of traffic signal timing plans and information signing for the predetermined routes; and use simulation software to develop and assess signal coordination plans along key evacuation and response/recovery routes.

APPENDIX A:

SEMORAN/LEE VISTA PHASING PLAN & CONTROL

CODE

CONTROLLER TIMING											
RING 1				RING 2							
APPROACH	NBL	SB	EBL	WB	SBL	NB	WBL	EB	PB?	Y	
DESCRIPTION	Semoran		Lee Vista		Semoran		Lee Vista		Rest/Walk?	N	
PHASE #	1	2	3	4	5	6	7	8			
INITIAL	7	15	7	7	7	15	7	7			
PASSAGE	3	3	3	3	3	3	3	3			
YELLOW	4	4.5	4	4	4	4.5	4	4			
RED CLEAR	1	1	1	1	1	1	1	1			
MAX 1	15	60	15	30	20	60	20	30			
MAX 2	10	65	10	49	10	65	10	49			
WALK		10		10		10		10			
PED CLEAR		41		38		39					
MIN RECALL		Yes				Yes					
MAX RECALL											
PED RECALL											
NON-LOCK	NL	Lock	NL	NL	NL	Lock	NL	NL			
REST IN WALK											
DISPLAY	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls			
U.C.F.	R	Y	R	R	R	Y	R	R			
MAIN ST.		Yes				Yes					
L/S POSITION	1	2	3	4	5	6	7	8			

North

East

West

South

	NB			SB			EB			WB		
	L	T	R	L	T	R	L	T	R	L	T	R
# of Lanes	1	3	1	2	3	1	1	2	1	1	2	1
Shared												
Width	12	12	12	12	12	12	12	12	12	12	12	12
Storage	240		240	240		240	240		240	240		240
Grade		0			0			0			0	
Posted Speed		55			55			35			35	
First Detect												
Last Detect												
Phase1	1	6		5	2		3	8		7	4	
Phase2												
Phase3												
Phase4												
PermPhase1												
PermPhase2												
PermPhase3												
PermPhase4												
DetectPhase1	1	6	0	5	2	0	3	8	0	7	4	0
DetectPhase2												
DetectPhase3												
DetectPhase4												
Det#1	1	0	0	0	2	0	3	0	0	0	4	0
Det#2		6		5				8		7		
Det#3												
Det#4												

Date Naztec Inspected: 5/23/2001

Work done by: Steve Jones

Intersection Number
245

Comm Channel
OLD 169
NEW

Intersection Name
Lee Vista

Semoran

NOTES: 1. Opticom programmed for all four (4) directions.

Revised 3/14/2005

APPENDIX B:

SEMORAN/T.G LEE PHASING PLAN & CONTROL

CODE

CONTROLLER TIMING												
RING 1				RING 2								
APPROACH	NBL	SB	EBL	WB	SBL	NB	WBL	EB				
DESCRIPTION	Semoran				T.G. Lee							
PHASE #	1	2	3	4	5	6	7	8				
INITIAL	7	15	7	7	7	15	7	7				
PASSAGE	3	3	3	3	3	3	3	3				
YELLOW	4	4.5	4	4	4	4.5	4	4				
RED CLEAR	1	1	1	1	1	1	1	1				
MAX 1	25	70	30	25	25	70	30	25				
MAX 2	10	65	10	53	10	65	10	53				
WALK		10		10		10		10				
PED CLEAR		34		43		34		43				
MIN RECALL		Yes				Yes						
MAX RECALL												
PED RECALL												
NON-LOCK	N/L	Lock	N/L	N/L	N/L	Lock	N/L	N/L				
REST IN WALK												
DISPLAY	Protected	Balls	Protected	Balls	Protected	Balls	Protected	Balls				
U.C.F.	R	Y	R	R	R	Y	R	R				
MAIN ST.		Yes				Yes						
L/S POSITION	1	2	3	4	5	6	7	8				

Date Naztec Inspected: 5/23/2001

Work done by: Dan Saile

Intersection Number: 352

Comm Channel: OLD 169, NEW

Intersection Name: Semoran

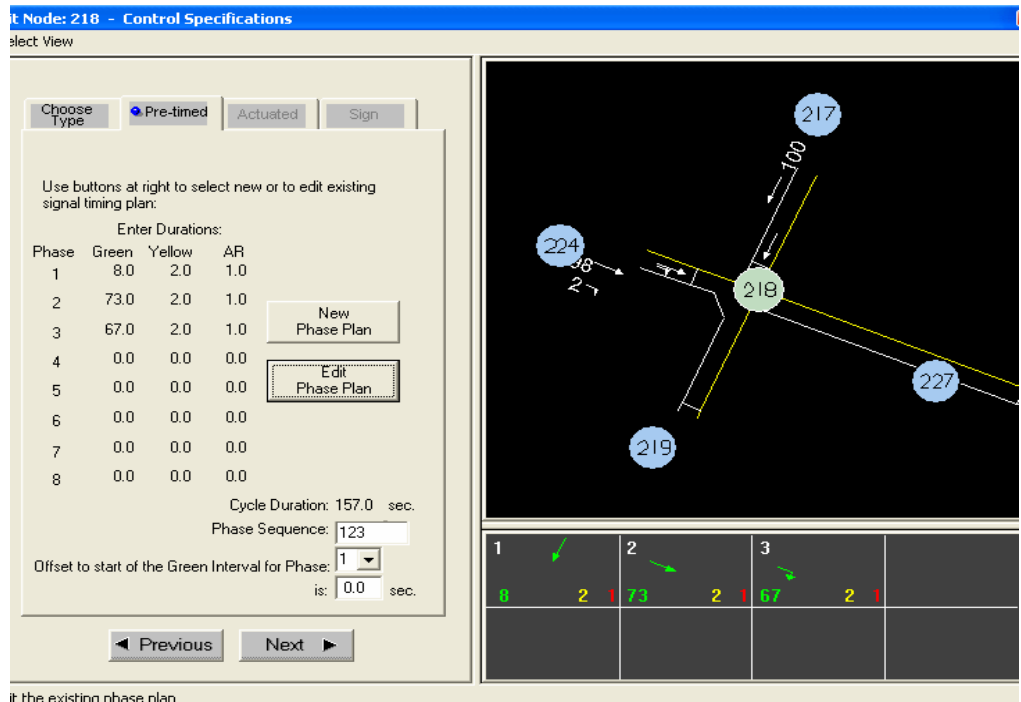
T.G. Lee/Frontage

	NB			SB			EB			WB		
	L	T	R	L	T	R	L	T	R	L	T	R
# of Lanes	2	3	1	1	3	1	2	1	1	1	1	1
Shared											R	
Width	12	12	12	12	12	12	12	12	12	12	12	12
Storage	240		240	240		240	240		240	200		200
Grade		0			0			0			0	
Posted Speed		55			55			30			30	
First Detect												
Last Detect												
Phase1	1	6		5	2		3	8		7	4	
Phase2												
Phase3												
Phase4												
PermPhase1										4		
PermPhase2												
PermPhase3												
PermPhase4												
DetectPhase1	1	6	0	5	2	0	3	8	0	7	4	0
DetectPhase2												
DetectPhase3												
DetectPhase4												
Det#1	1	6	0	5	2	0	3	8	0	7	4	0
Det#2												
Det#3												
Det#4												

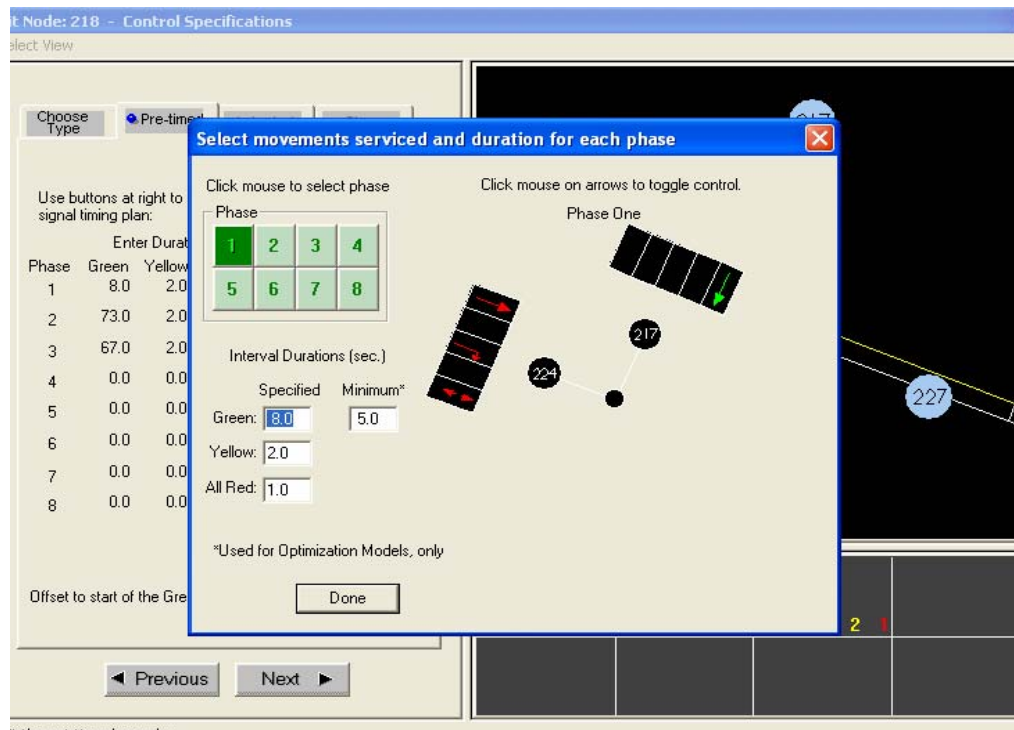
NOTES : 1. Opticom is programmed for all four (4) directions.

Revised 3/14/2005

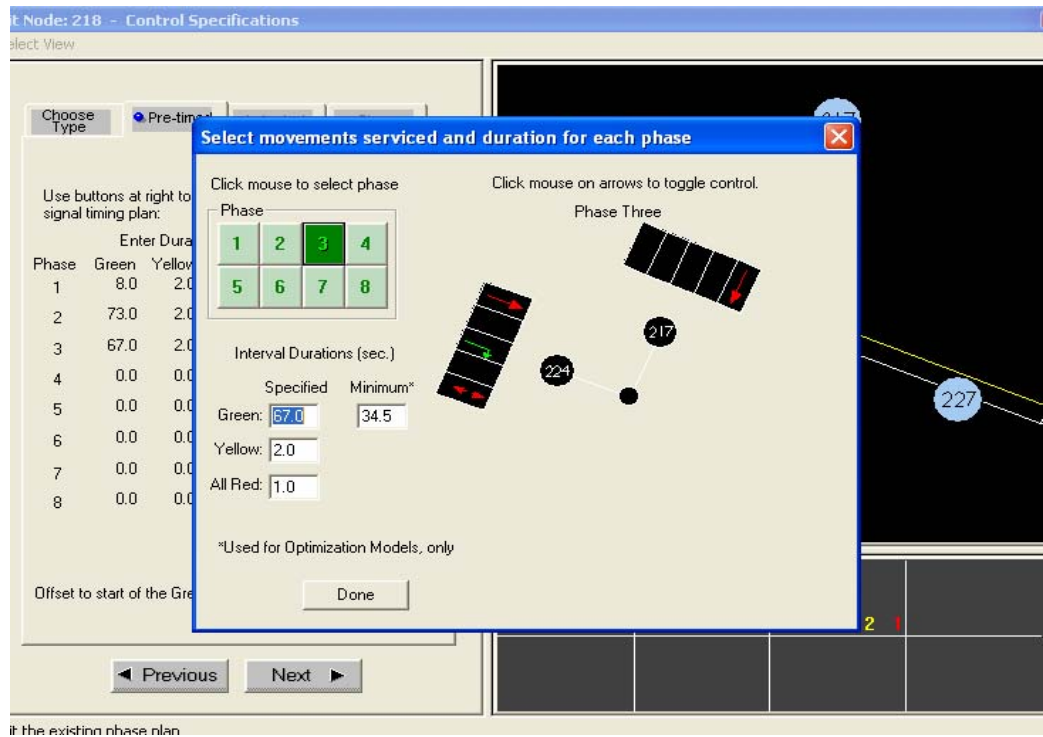
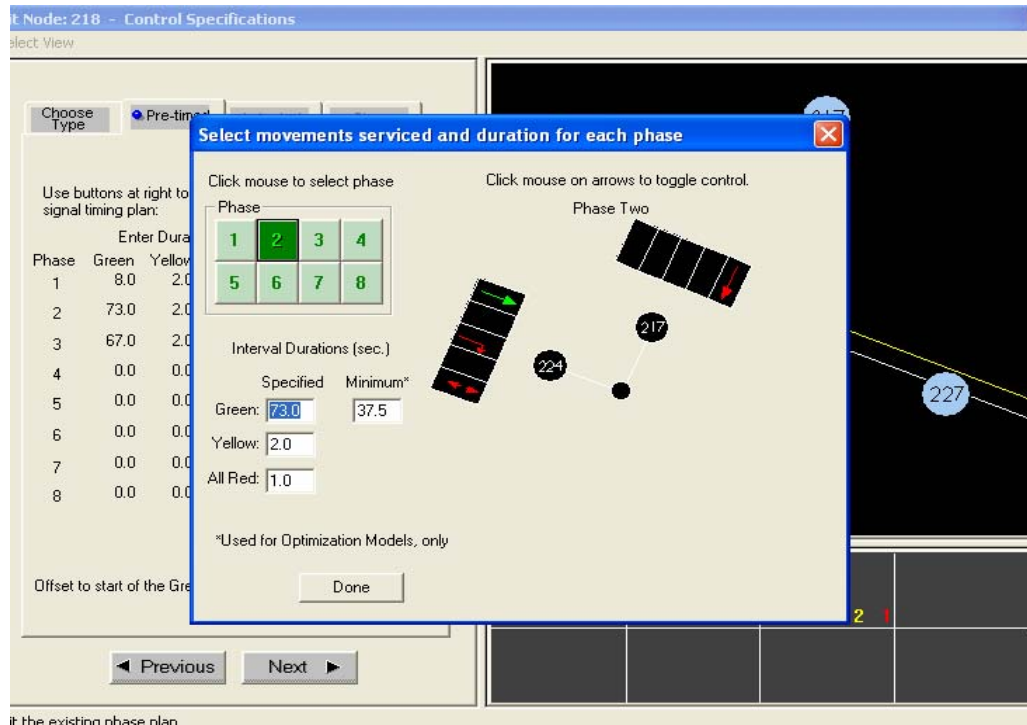
APPENDIX C:
SECURITY CHECKPOINT PHASING PLAN &
CONTROL CODE



it the existing phase plan



it the existing phase plan



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